

1-1-1983

Manipulation of stimulus onset delay in reading: evidence for parallel programming of saccades.

Robert Earl Morrison
University of Massachusetts Amherst

Follow this and additional works at: https://scholarworks.umass.edu/dissertations_1

Recommended Citation

Morrison, Robert Earl, "Manipulation of stimulus onset delay in reading: evidence for parallel programming of saccades." (1983). *Doctoral Dissertations 1896 - February 2014*. 1721.
<https://doi.org/10.7275/59cg-vf41> https://scholarworks.umass.edu/dissertations_1/1721

This Open Access Dissertation is brought to you for free and open access by ScholarWorks@UMass Amherst. It has been accepted for inclusion in Doctoral Dissertations 1896 - February 2014 by an authorized administrator of ScholarWorks@UMass Amherst. For more information, please contact scholarworks@library.umass.edu.

312066013295766

MANIPULATION OF STIMULUS ONSET DELAY IN READING:
EVIDENCE FOR PARALLEL PROGRAMMING OF SACCADDES

A Dissertation Presented

By

ROBERT EARL MORRISON

Submitted to the Graduate School of the
University of Massachusetts in partial fulfillment
of the requirements for the degree of

DOCTOR OF PHILOSOPHY

September 1983

Psychology



Robert Earl Morrison

All Rights Reserved

MANIPULATION OF STIMULUS ONSET DELAY IN READING:
EVIDENCE FOR PARALLEL PROGRAMMING OF SACCADDES

A Dissertation Presented

By

ROBERT EARL MORRISON

Approved as to style and content by:

Keith Rayner

Keith Rayner, Chairperson of Committee

Alexander Pollatsek

Alexander Pollatsek, Member

Arnold D. Well

Arnold D. Well, Member

Stanley M. Moss

Stanley M. Moss, Member

Allen R. Hanson

Allen R. Hanson, Member

James M. Royer
James M. Royer, Department Head
Psychology

Dedicated to Terry, my wife, for the unflagging confidence and support which sustained me throughout this endeavor.

ACKNOWLEDGEMENTS

I wish to express my deep gratitude to my dissertation committee, especially Keith Rayner, chairperson, and Sandy Pollatsek; also Arnie Well, Stan Moss, and Allen Hanson.

I also thank the National Institutes of Health for support provided under Grant HD12727, and the University of Massachusetts' Department of Psychology for research support.

ABSTRACT

Manipulation of Stimulus Onset Delay in Reading:

Evidence for Parallel Programming of Saccades

September 1983

Robert E. Morrison, B.S., Union College

M.S., University of Massachusetts, Ph.D., University of Massachusetts

Directed by: Professor Keith Rayner

On-line eye movement recording of twelve subjects who read short stories on a cathode ray tube enabled a test of direct control and preprogramming models of eye movement control in reading. Contingent upon the eye position, a mask was displayed in place of the letters after each saccade, delaying the onset of the stimulus in each eye fixation. The duration of the delay was manipulated in fixed or randomized blocks. Although the length of the delay strongly affected the duration of the fixations, there was no difference due to the conditions of delay manipulation. Also, not all fixations were lengthened by the period of the delay; some ended while the mask was still present. These anticipation eye movements were not totally oblivious to the mask, though. Their fixation durations and saccade lengths were affected by the spatial extent of the mask, which varied randomly. The data supported neither preprogramming or existing serial direct control models of eye guidance. Instead, a model with direct control and parallel programming of saccades is proposed to explain the data, and eye movements in reading in general.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS	v
ABSTRACT	vi
LIST OF TABLES	ix
LIST OF FIGURES	x
Chapter	
I. INTRODUCTION	1
The Timing Question	6
Preprogramming Versus Direct Control	14
Manipulating Stimulus Onset Delay	21
II. METHOD	28
Subjects	28
Apparatus	28
Stimuli	29
Procedure	30
Experimental Design	31
III. RESULTS AND DISCUSSION	33
Reading Comprehension	33
Fixation Duration	34
Global Analysis	34
Local Analysis	43
Saccade Length	54
Global Analysis	54
Local Analysis	56
IV. GENERAL DISCUSSION	59
Current Models are Repudiated by Data	59
Parallel Versus Serial Programming	63
The Role of Attention in Eye Guidance	71
Outline for an Eye Control Model Incorporating Parallel Programming of Saccades	75
FOOTNOTES	86
REFERENCE NOTE	87

REFERENCES	88
APPENDIX A	96
APPENDIX B	98
APPENDIX C	119

LIST OF TABLES

1. Comprehension scores achieved at each condition of SOD manipulation	33
2. F-ratios from ANOVAS on data in Figure 7	51
3. Mean forward saccade length analyzed on the basis of the pre- vious fixation duration relative to the duration of the SOD	57
4. Mean fixation duration as a function of stimulus onset delay and mask size across all SOD manipulations	96
5. Percentage of anticipations as a function of stimulus onset delay and mask size across all SOD manipulations	97

LIST OF FIGURES

1. Mean fixation duration as a function of stimulus onset delay and mask size in the blocked and random-equal conditions	35
2. Percent anticipations as a function of stimulus onset delay and mask size	40
3. Number of fixations per line of text as a function of stimulus onset delay in the blocked condition	42
4. Histograms of fixation duration at each stimulus onset delay in the random-equal condition	44
5. Fixation duration histograms showing size of following saccade	46
6. Fixation duration histograms showing size of the mask	48
7. Mean fixation duration and quartile fixation durations as a function of stimulus onset delay and mask size in the random-equal condition	50
8. Mean forward saccade length as a function of SOD and mask size in the blocked and random-equal conditions	55

CHAPTER I

INTRODUCTION

Research employing eye tracking techniques to study the reading process enjoys a long history in human experimental psychology. Early studies of eye behavior in reading were primarily descriptive (Dearborn, 1906; Huey, 1908). Conclusions about the reading process and the role of eye movements therein were inferred from trends or regularities noticed in eye movement records. Later investigators studied how stimulus variables affected eye movements. Predictable changes in eye behavior were found with variations in both text difficulty (Buswell, 1937, 1939) and typographical aspects of the text (Tinker, 1946, 1958), but these could only be demonstrated on a global level, in average values of the various parameters.

Recent research has gone beyond globally descriptive work to attempt to define the precise, local nature of information processing and eye movement control during individual eye fixations in reading. An investigative assault on such a continuous, flexible, and private activity as reading has been possible only with recent technological developments, mainly the mini-computer, which can score data from an eye movement recording apparatus on-line and concurrently manipulate the presentation of stimuli on a cathode-ray tube (CRT) as a function of the eye position information (Rayner, 1979a).

The technique of on-line eye contingent display change (Reder, 1973), first employed by McConkie and Rayner (1975), is a powerful tool for studying reading because the information a reader has access to can be precisely controlled in both spatial and temporal dimensions at the level of individual eye fixations, while still allowing the reader to read "naturally" (McConkie, Zola, Wolverton, & Burns, 1978). Indeed, the logical appeal of the paradigm is that the point at which the experimental intervention just begins to do damage to the reading process, as indicated by changes in eye behavior from a control condition containing no display manipulation, defines the threshold for the influence of the manipulation and allows us to infer the spatial and temporal nature of the information processing activities occurring.

The eye contingent display change paradigm has been quite successful in determining the spatial metrics of information processing during reading. McConkie and Rayner (1975) mutilated the text displayed to a reader except for that within a "window" of variable size around the momentary fixation point. The window provided readable text while the "periphery" was composed of various mutilations of the original text. Not surprisingly, very small windows of only a few letters disrupted reading dramatically. The interesting finding was that the window did not have to be very large to not derail the reading process, nor was the mutilation in the periphery then noticed by the reader. In cases where the window did not hamper reading, one can infer that all the information the reader uses - the perceptual span - is located within the region of the window. Decreasing window

size until performance just starts to decline identifies the maximal size of the perceptual span. It is possible to mutilate only certain kinds of information while maintaining other kinds in the periphery (e.g., maintaining blank spaces between words but changing all the letters to a different one), in effect, running a condition with two separate windows for two kinds of information. This permits the determination of separate perceptual spans for different kinds of information, such as word length or specific letter information.

Studies doing exactly this have been quite successful in showing that the perceptual span is asymmetric, starting at the beginning of the currently fixated word (Rayner, Well, & Pollatsek, 1980) and generally extending about 4 - 6 letters to the right of the fixation point for semantic identification, to about 10 letters to the right for information about specific letters, and up to about 15 letters to the right for word length and spacing information (McConkie & Rayner, 1975; Rayner, 1975). This is for left-to-right reading, as in English. When reading a right-to-left language such as Hebrew, the perceptual span is reversed, thus asymmetric to the left (Pollatsek, Bolozky, Well, & Rayner, 1981).

Converging evidence has been provided by experiments employing the opposite of a window - a mask moving in synchrony with the eye, blocking central vision but leaving intact the text in the periphery (Rayner & Bertera, 1979; Rayner, Inhoff, Morrison, Slowiaczek, & Bertera, 1981). This manipulation definitely hampers reading, even in its least invasive form (masking only the one character in the center

of vision decreases reading speed by 50%; Rayner & Bertera, 1979). But information is still extracted from the area outside the central mask and the parameters of the information extraction agree with the estimates of the perceptual span derived from the window experiments. For instance, if the mask is small (1-5 letters) the reader can still completely identify the words and read. As mask size increases, filling up foveal and near parafoveal vision, semantic identification becomes poorer and fewer words are identified. Short function words may be seen but the reader essentially guesses at content words on the basis of limited information that can still be acquired from extrafoveal vision. This is word length, word shape, and some specific letter information. The reader's incorrect guesses match the actual text in this way (e.g., fuzzy is misread as funny; Rayner & Bertera, 1979). When the mask extends beyond about 7 letters to the right of the fixation point very little information can be extracted and reading effectively ceases.

The most recent use of eye contingent display change has been to elucidate the temporal metrics of information processing during eye fixations in reading. Such questions as: when are certain kinds of information obtained from the text, how long does visual processing of the stimulus take, and when are decisions to move the eyes made, can be addressed by presenting the masks or windows for only certain periods of time within individual eye fixations.

Rayner, et al. masked the text in central vision after it was initially displayed for various intervals. They found that if the text

was displayed for 50 msec before the mask came on, reading performance was basically the same as if no mask came on at all. It was concluded that as little as 50 msec of processing of the visual stimulus is necessary in order to encode it into some form impervious to masking. Thus about 50 msec of a fixation may be all the time needed for processing visual features of the stimulus. Recently, Pollatsek and Rayner (1982) have provided evidence that word spacing information (i.e., word length) in parafoveal vision is also processed sufficiently within a 50 msec period such that subsequent masking does not hinder reading. They conclude that this information, which is used to guide the eyes to the next fixation location, is fully processed and perhaps the spatial decision of where to place the next eye fixation is made after only 50 msec processing of the stimulus.

The opposite of the delayed masking paradigm, a condition where a mask is initially displayed but then removed some time during the fixation to expose the text has recently been used to investigate the temporal decision in eye guidance as well (Rayner & Pollatsek, 1981). This manipulation delays the presentation of the textual stimulus on each fixation. Thus, the independent variable, the length of time the mask is on is called the stimulus onset delay (SOD). The technique has been used by Vaughan and his colleagues in studies of visual search (Vaughan & Graefe, 1977; Vaughan, 1978, 1982, 1983) and Rayner and Pollatsek (1981) in reading experiments. Both investigations were concerned with resolving a long standing dispute about eye control in information processing, namely, whether or not timing constraints are

too severe to permit an influence on saccadic programming by cognitive processes occurring in the preceding fixational pause.

The Timing Question

The now familiar dilemma caused by the relative brevity of eye fixations and the apparent complexity of the cognitive operations involved in eye control led the literature to diverge into two classes of eye control models, separated according to how they answer the question, "Can the eye react immediately to what it sees?" (Levy-Schoen & O'Regan, 1979, p. 25). The immediate control position maintains that decisions to move the eyes are made during the immediately preceding fixation period on the basis of the currently perceived information. Since the neurological operations mediating eye movements take significant and measurable time, I prefer the term "direct control" (Rayner & Pollatsek, 1981) and will use it instead of immediate control. Direct control simply means that information first processed on fixation N can affect the initiation and size of the saccade that terminates fixation N and ushers in fixation N + 1. On the other hand, the delayed control models assert that fixation pauses are too brief to encompass information uptake, decision processes, and the reaction time to move the eye; eye movement decisions are not based directly on the processing of the stimulus in the current fixation. Instead, some other process-monitoring entity adjusts the frequency and/or amplitude of eye movements as a function of how effectively reading has been proceeding. This control will be influenced only by

information "buffered" in a short term store, having been obtained on preceding fixations. Hence, information derived on fixation N can only affect the spatial or temporal location of fixation N + 2 at the earliest.

Delayed control theories postulate not only a lag between information uptake and control of eye behavior by such information, but a lack of dependence between the command to move the eyes (both when and where) and the processing of any information seen at that time. If eye control is dissociated from visual processing states then some other mechanism must be assumed to trigger changes in eye position. One possibility is an internal timer of sorts initiating saccades at a more or less constant rate. This notion has been suggested by the work of Cunitz and Steinman (1969). They found that the distribution of fixation durations in reading is very similar to that found when subjects simply look at the letter "T". In both situations fixation durations average around 300 msec, with a fairly wide range of variability. It could be that all saccades are controlled by a single system. Thus, an inherent neural mechanism, although rather noisy, may trigger an eye movement every 300 msec on the average, regardless of the kind of task being performed. Cunitz and Steinman found that fairly long fixation durations of about 500 msec commonly observed in reading are usually two shorter fixations on the same word separated by a microsaccade at about 250 - 300 msec. Similar notions have been offered by reading theorists (Bouma & de Voogd, 1974; Kolers, 1976) who postulate that the eye advances over the text at a fairly constant rate

and, additionally, the rate mechanism may be slowed down or speeded up (on a delayed basis) depending upon how much difficulty the reader is having decoding the text. Even if the adjustment occurs fairly quickly, if it is delayed by one eye movement it is not direct control.

Another type of non-direct control theory postulates that eye movements are already programmed to occur before the preceding fixation pause actually begins. Such "preprogramming", by definition assumes no influence on the next eye movement from information obtained during the current fixation because that decision has already been made. Preprogramming is supposedly an efficient cognitive strategy because it eliminates dead time at the end of a fixation which would occur with direct control, where the long reaction time of the oculomotor response must follow the processing of the stimulus (Russo, 1978). By preprogramming the fixation durations to a value long enough on average for the processing of the stimulus to be completed, the dead time is substantially reduced. The two kinds of models of delayed control described are somewhat complementary. Process-monitoring delayed control is saying that saccades can only be guided by information from previous fixations because fixations are so brief. Preprogramming claims that fixations are made brief and efficient by preprogramming eye movements at an earlier time, logically of course using only the information available up to that point.

Intimately related to the whole question of timing on which the preprogramming - direct control controversy hinges is the issue of oculomotor latency, which likewise has been a point of debate (c.f.

Just & Carpenter, 1980, and Rayner & Pollatsek, 1981). Total oculomotor latency includes the afferent lag required for peripheral excitation to traverse neural pathways connecting with central structures, some decision stage for defining and programming the appropriate spatial parameters of the response, and an efferent latent period that must elapse between the internal event which triggers an eye movement and the actual jerk of the eye. Although there is a consensus that the afferent latency is between 40 - 60 msec, estimates for the remaining stages differ markedly. This is in part because their very nature is unclear. Some authors (Just & Carpenter, 1980) believe the time to initiate an eye movement is short relative to total fixation duration and does not constitute a difficulty or bottleneck in information processing that would negate direct control. Just & Carpenter claim the latency from the central command until the eye moves is about 30 msec, but their model is vague as to the nature and possible duration of decision processes linking the afferent and efferent stages.

Many researchers (Rayner & Pollatsek, 1981; McConkie, 1983; Zola & Wolverson, 1983) disagree with Just and Carpenter's model, citing an increasing body of evidence showing that a stimulus presented less than about 150 msec before the end of a fixation will not affect the upcoming eye movement decision (Rayner & Pollatsek, 1981; Zola & Wolverson, 1983), but will have an effect only on the next fixation. If this is the minimal total latency for a stimulus to impact upon eye behavior, then subtracting out the 50 - 60 msec afferent latency leaves

90 - 100 msec as the minimal latency for the programming process and afferent delay (Russo, 1978).

Since a fair number of fixation durations in reading are less than 150 - 200 msec, the estimate implies that for many fixations saccades are initiated very early in the period and over half of the fixation is spent waiting for the eye to move (Russo, 1978). Since afferent latency must still be taken off the front end very little time would be left over for processing stimulus information in order to determine where to move the eye. Preprogramming is suggested as a method of optimizing a system with such limitations (Russo, 1978). Indeed a reasonable direct control model would probably have to exempt these rather brief fixations from consideration (McConkie, 1983). Of course, doing so weakens the explanatory power of direct control. By attempting to model the control of fixations of "average" duration, this problem is often overlooked.

The very term preprogramming reveals a tacit commitment to a serial programming model of fixation-saccade commands in eye movement control. For to pre - program something is to program it in advance of when the program will actually be used. In eye control, this would mean programming a saccade and holding this program in abeyance until it is appropriate to run the program. The view of discrete fixation-saccade cycles is a natural one to draw because the eyes do move as such and saccadic suppression constrains the periods of information uptake to discrete, non-overlapping "windows". The conception was seemingly necessitated by a related assumption that a

retinal error signal is used to define the metrics of a saccade, implying that eye movement initiation cannot begin until after the fixation has been processed and the retinal error is known.

However, saccades are spatiotopically organized as has been convincingly demonstrated in psychophysical experiments by Hallett and Lightstone (1975) and in neurophysiological work by Mays and Sparks (1980). This means the program for a saccade defines a certain final position in space for fixation as opposed to a certain degree of eye rotation. If the eye is shifted after the initial input of information but before the actual saccade the specific neuromotor commands can be updated to achieve the proper final eye position. For example, Hallett and Lightstone briefly flashed a target to subjects who were in the middle of saccadic eye movements. By the time the afferent stimulation reached central loci the eye would have moved, the saccade most likely completed by then. With the eye now in a different position from the moment it was stimulated the retinal error between eye and target position did not equal the actual error which needed correction. Yet subjects were able to accurately fixate the target position with perfectly normal latency. This proved that eye movements operate to correct the existing eye position to target position discrepancy, not to rotate the eye by the amount of error existing at the time the retina was stimulated. Of course, this means that when the eye moves during the latent period before a saccade, the new eye position information has to be incorporated fairly quickly, at a relatively peripheral layer of the system in order to update the spatiotopic

signal in time to make the correction. Though lacking until recently, physiological evidence for such coding has now been elegantly demonstrated by Mays and Sparks in the primate superior colliculus. Since the efferent latency from the superior colliculus is about 30 msec, new stimulus information can be integrated here fairly late in the latent period and still allow a correct eye movement.

The spatiotopic organization of the saccade generator means that serial control is not required on logical grounds. Control could be parallel in principle. Indeed, it has been known for some time that a saccade can be prepared to a target while a saccade to an earlier target is still being initiated (Wheless, Boynton, & Cohen, 1966). Programming for one saccade may even catch up with and cancel an earlier one under certain conditions. This phenomenon has become better understood in light of recent psychophysical research utilizing double-step stimuli, a paradigm wherein a simple target to be tracked jumps to a peripheral location and then may jump a second time before a response to the first jump has been made. If the second step occurs quickly, far enough in advance of the eye movement to the first step, processing of the second response can partially or completely modify the first and the eye will saccade towards the final target position (Becker & Jurgens, 1979). The length of this latent period after the second step but before the saccade to the first step is a more reliable predictor of modification of the first response than the simple interstimulus interval. Furthermore, the exact temporal parameters necessary for such interactions vary quite widely depending upon the

spatial relationship of the target jumps. For example, in one condition Becker and Jurgens found that the saccade to the first step could still be modified when the second step occurred just 80 msec prior to the saccade. But in another condition where the target jumped across the midline to the opposite visual field, it had to occur no less than 170 msec prior to the onset of the first saccade in order to modify it. Of course, when the first saccade can not be modified two completely independent eye movements occur, mimicing the double-step of the target. However, the second saccade need not wait for visual reafference after the first eye movement, but is initiated on the basis of the original stimulation received prior to the first. Thus, the second saccade can follow the first very closely, appearing to have an extremely short latency (if that is defined as the fixation pause between the two movements).[1]

Becker and Jurgens (1979) have demonstrated that the phenomenon is in fact parallel programming of saccades; they note that the critical temporal variable determining the amount of parallel programming is not the time between the target steps, but the time between the second target step and the saccade to the first target step, which is a stochastic variable, because the response time of the eye is. The longer this interval is, the higher the probability that parallel programming will occur, and that there will be a lot of overlap in the programming of the two saccades. Of course, with a long opportunity for parallel programming, the higher the likelihood that the response will be towards or directly to the second target, that is, that the

second saccade will overtake the first. When parallel programming occurs without any interaction of response, giving two independent saccades, the longer the parallel programming interval is, the shorter the subsequent fixation duration is because the actual oculomotor latency is fairly regular but has simply begun earlier in the preceding fixation. The reason saccades may be programmed in parallel is that programming consists of more than a single stage. Totally independent responses can be prepared at the same time provided they don't compete for the same stage; one response must be somewhat ahead of the other; If they do compete for the same stage, the two responses will not remain independent - they will interact with each other. Thus, extremely short intersaccadic pauses only reflect a brief time between the commencement of the programming of two eye movements, not a super fast latency for the second one. A serial chain of fixation saccade cycles is not the only mode of eye guidance, although that is not to deny that it may operate in this fashion more often than not.

Preprogramming Versus Direct Control

Preprogramming has recently received a lot of attention due to experiments reported by Vaughan and Graefe (1977) and Vaughan (1978). Vaughan and Graefe had subjects alternate fixation between two locations searching for a target letter. After the eye landed at either location the letter presentation was delayed for a variable amount of time. Fixation durations would presumably be lengthened by the amount of the delay if direct serial control was operating, because

the subject would simply have to wait out the delay period in order to begin processing the stimulus and subsequently initiate an eye movement. Surprisingly, with short stimulus onset delays, fixation duration did not increase but remained fairly constant. Therefore, the time between the beginning of the letter presentation and the occurrence of the saccade became shorter as SOD increased. Vaughan inferred that the duration of a fixation was independent of the time spent processing the stimulus in a fixation and thus must be preprogrammed. Fixations were preprogrammed to a duration which allowed the proper processing of visual information in order to perform the task on most occasions but cut the dead time of oculomotor latency to a minimum by not waiting for the letter to be presented and processed before deciding when to make the next saccade. Vaughan and Graefe offered arguments and evidence which seemed to make preprogramming the most parsimonious explanation for their data - indeed their result is an unintuitive one.

However, using the same paradigm, Vaughan (1982, 1983) has recently found increases in fixation duration due to stimulus manipulations that lengthen the required processing time on individual fixations. This is evidence against preprogramming and for direct control. He concludes that the earlier data showing no increase in fixation duration with increases in SOD are due to the prior saccade serving as a warning signal to the subsequent one, with a foreperiod or warning signal effect speeding both stimulus processing and the directly controlled oculomotor reaction time following the processing

of the stimulus. Vaughan maintains that preprogramming is still a viable strategy, however, and may operate in reading. For instance, the perception of the length of the upcoming word in parafoveal vision on one fixation could be used to estimate the processing time required for that word on the next fixation and a fixation of such duration could be preprogrammed (see also Russo, 1978). The subsequent foveal inspection of the word would have no influence on the already-determined fixation duration. Other situations in reading wherein more than one eye movement may be programmed at a time during reading have been suggested by Rayner and Pollatsek (1981), Levy-Schoen and Blanc-Garin (1974), and Leisman (1978).

Rayner and Pollatsek (1981) used eye contingent display change to investigate the possibility of direct versus delayed control (or preprogramming) during reading. Previous data from Rayner and his colleagues showed that fixation durations and saccade lengths were sensitive to the window and mask sizes employed in their experiments. But because the various window or mask sizes had been presented in separate blocks of trials, additional evidence was needed before concluding that the data reflected direct control of ocular responses to the stimulus within each fixation, as opposed to delayed control via a global adjustment to the block, or preprogramming. To this end Rayner and Pollatsek manipulated window size in two conditions: fixed in blocks or varied randomly from fixation to fixation. If eye movement decisions are made within each fixation as a function of information currently seen, parameters such as saccade length should be

affected by window size equally in either condition. On the other hand, if only delayed control is possible or if preprogramming of saccade length is necessary because of the brevity of fixations usually found in reading, then saccade length would not vary as a function of the momentary window size in the variable delay condition since this cannot be known until the information from the fixation is processed. Rayner and Pollatsek's data supported the view that saccade length is controlled directly: mean saccade length varied with the size of the window almost identically in the fixed and variable conditions. Interestingly, they also found that saccade length in the variable condition was affected by the size of the window on fixation $N - 1$. They concluded that saccade length is controlled by information from prior fixations as well as the current fixation.

Rayner and Pollatsek also created a stimulus onset delay via a central mask and looked at the effects on fixation duration. In particular, SOD was held constant for a block of trials or varied randomly from fixation to fixation to see if fixation durations were under immediate or delayed control. Presumably the delay of the text due to the mask simply interspersed pauses in the reading process without affecting any qualitative change in the process itself. In general, they reported that fixation duration increased by an amount nearly equal to the delay of the stimulus in both fixed and variable conditions. It appeared for the most part that subjects simply waited out the mask on each fixation before the processing cycle began, and eye movements were only programmed after processing had been completed

to some level. The occurrence of the saccades did not seem rhythmic or determined without regard to the stimulation received within a fixation. But this exists as a complete picture of the data at the shorter SODs only. At long SODs Rayner and Pollatsek reported evidence that suggests preprogramming is sometimes used, or at least that the processing of the stimulus in a given fixation does not affect the duration of that fixation. In conditions with long SODs (200 and 300 msec) the eyes sometimes moved before the delay period ended, thus without ever having seen the masked text. This resulted in a bimodality of fixation durations. Because these eye movements appear to decide prematurely how long the fixation should last and when the eye should move again they are called anticipations. They appeared to occur without regard to any processing of the stimulus during the fixation, perhaps triggered at the normal timing interval by some constant-rate mechanism and not cancelled out when the stimulus failed to appear, or they may have been preprogrammed during the previous fixation.

The bimodal distribution of fixation durations raises questions about the interpretation of changes in the mean fixation duration in terms of underlying processes. Fixation durations have traditionally been viewed as unimodal, quasi-normally distributed values generated by some common process. Fluctuations from the average value are assumed to represent both random error and real chronometric effects associated with cognitive operations. Very brief fixations, around 100 - 150 msec say, would represent the extreme lower tail of this distribution. This

is assuming also that such are really discrete fixations and not an artifact caused when a longer fixation is contaminated by drift which the eye monitoring apparatus scores as a saccade. However, many of the very brief fixations are bounded by saccades of normal size and must be psychologically real. To reconcile these with a serial direct control model they must be regarded as fixations followed by saccades with unusually short but not impossible latencies (or they can be ignored - many eye tracking algorithms set arbitrary minima on the duration of fixations and will fail to detect any shorter than this). Increases in average fixation duration are often assumed to shift the entire distribution of fixation durations upward by the amount of the increase in average fixation duration (Rayner, Slowiaczek, Clifton, & Bertera, 1983). Thus a 50 msec SOD which raises mean fixation duration by approximately 50 msec is assumed to operate by delaying the start of a serial chain of activities at the beginning of each and every fixation for 50 msec. Rayner & Pollatsek report nearly equal compensation of fixation duration for SOD at short delays. However, the bimodal distribution of fixation duration at long delays suggests that two different populations may contribute to the obtained distribution of fixation durations, in all cases. One population may consist of fixation durations reflecting cognitive processing of the text seen in central vision, the other may consist of those which do not. If this is the case, then the seemingly perfect compensation of fixation duration for SOD may be a fiction. It is possible that those fixations sensitive to the mask may be lengthened by more than the SOD; the

weighted mean of these with the fixation durations that are not influenced could fortuitously show an increase of about the same magnitude as the SOD.

There also exist alternative explanations for anticipatory saccades which do not necessitate the abandonment of direct control in favor of preprogramming. Since the long SODs are longer than many fixation durations occurring in control conditions, and thus longer than the reaction time of the eye (if those fixations are indeed directly controlled), it is possible that the anticipatory saccades were made in response to the stimulation received during that fixation: That is, they are an immediate response to the masking stimulus in foveal vision. In short, a tendency of the eye to "get away from the mask" may occur.

Eye contingent display changes involving foveal masks present the subject with a complex and unnatural situation. As Rayner and Bertera (1979) have noted, the situation mimics that of a foveal scotoma. Every time the eye moves so does the mask, by a like amount. Although the size and duration of the mask are chosen by the experimenter as an independent variable, the individual occurrence of each mask is a contingent variable, dependent upon and following in time-locked fashion the preceding saccade (Reder, 1973), which is, of course, one of the dependent variables produced by the subject that we are interested in observing. The subject has been placed in a feedback loop with the on-line eye tracking and display change apparatus.

It may be incorrect to view the mask as simply an instrument whereby the processing of the text within a fixation is delayed for a certain period during otherwise normal reading behavior. Anticipatory saccades may not reflect normal reading responses, but a behavioral adjustment to cope with the unnatural and frustrating situation of having foveal vision blocked for long periods of time. Previous experiments in which eye behavior adjusts to compensate for the effects of eye contingent display changes have been reported by McLaughlin (1967) and Henson (1978). These dealt with shifts in the position of a target occurring as the subject made a saccade to that target, causing an overshoot. When exposed to such a situation repeatedly, subjects reduce the amplitude of their saccades to correctly land on the target even though the shift always occurred during the saccade. In Rayner and Pollatsek's experiment it may be that the anticipatory saccades were an immediately controlled, automatic adjustment aimed at "shaking off" the foveal mask. (These would be like the nystagmus exhibited by people born without retinal cone receptors, that is, with complete foveal scotomas; Duke-Elder, 1973.) If the anticipations are an adaptative behavior they should be sensitive to the likelihood of a long mask.

Manipulating Stimulus Onset Delay

The experiment to be presented was designed to test whether the source of control for anticipations is preprogramming or direct control, in order to avoid the mask. This was done by comparing the

proportion of anticipatory saccades at long stimulus onset delays in both fixed and variable stimulus onset delay conditions during a reading task.

Rayner and Pollatsek ran blocks of sentences with SODs of 25, 50, 100, 200, and 300 msec in the fixed delay condition and obtained the anticipatory saccades with the 200 and 300 msec delays. In the variable delay condition the SOD on any fixation was randomly set at either 25, 50, 75, or 100 msec. Since long SODs were not included in the variable condition, anticipatory saccades were not available for analysis and no comparison of anticipations between fixed and variable conditions can be made.

Of course, in the fixed condition with long SODs the foveal mask would be on for 200 or 300 msec on each and every fixation. In order to do any foveal processing the eye would have to remain still for more than say, 300 msec. In fact, many fixations did seem to be of normal duration plus an additional 300 msec. Subjects may have had to exert conscious control to hold the eyes still in order to counteract an automatic response to "beat the mask". The two competing tendencies would account for the bimodal distribution of fixation durations Rayner and Pollatsek found. The bimodal distribution could also be seen as composed of fixations ended by saccades triggered at normal timing intervals by a constant-rate mechanism and longer fixations occurring when conscious control held the eyes still, overriding the inherent tendency to move. Of course, when SOD is varied randomly it could be advantageous to make, rather than inhibit, anticipatory saccades in

response to a long SOD, because initiating a new fixation might elicit a mask with a very short SOD, which would provide a glimpse of foveal text sooner than if the long SOD were waited out. This would increase reading speed overall by eliminating a lot of dead time spent waiting out the long delays. Thus, more anticipations at the long SODs would be expected in a variable condition if either anticipatory saccades were made in response to the perception of a long duration foveal mask, or if they are generated rhythmically and the system has some degree of inherent flexibility allowing performance optimization.

Flexibility in the proportion of anticipatory saccades across different experimental conditions would also be consistent with the preprogramming notions of Vaughan and Graefe (1977). They would predict more anticipations in variable SOD conditions because the fixations are programmed to a medium duration relative to the delays used, in order to provide enough processing time for most fixations yet without allowing so much of a cushion as to result in substantial dead time on many fixations, either. As a result, fixations receiving the shortest delays tend to include a little dead time, while those receiving the longest delays tend to have not quite long enough durations, including cases of anticipations where the eye moves before the stimulus ever comes on. In a fixed delay condition, since the durations are preprogrammed to allow for the single delay exactly, the durations compensate the delay just enough (Vaughan, 1978) so there should be few if any anticipatory saccades. One might argue then, that no anticipations should have occurred in the Rayner and Pollatsek

experiment because the presentation of delays was fixed, as noted earlier. This is not necessarily so. There is no reason that subjects should be able to exert perfect control over their eye behavior (it is an automatic process of which we are not usually conscious), especially subjects that are not highly practiced. Vaughan's subjects were rather well practiced, while Rayner and Pollatsek's subjects saw blocks of only eight sentences at each SOD and may not have received enough training to further reduce the proportion of anticipations at each SOD. Also, some of the anticipations may actually have been slow drifts which caused a large enough deviation of eye position over the long delay period so that the eye monitoring algorithm scored it as a saccade. Rayner and Pollatsek found that about half of the anticipations were less than one character space in extent and may represent these kind of artifacts. Presenting longer blocks would allow a slow-developing practice effect to emerge, if anticipations are hard to suppress until a great deal of experience has been gained.

In order to discriminate between preprogramming and immediate control, expectancies for the various delays presented in the variable SOD condition were manipulated. Besides a condition in which long and short delays occurred randomly with equal probability, sequences were employed in which the proportion of short delays vastly exceeded that for long delays, or vice-versa, causing a short delay expectancy or a long delay expectancy, respectively. When long SODs are encountered in a short expectancy block any anticipation saccade would very likely begin a new fixation suffering only a short delay, and thus would not

be undesirable, by the earlier argument. On the other hand, in a long expectancy block a long delay would most probably be followed by another long delay so an anticipation might not gain anything. Therefore, anticipatory eye movements might be suppressed to a greater degree in this case, as it approaches the completely blocked long delay condition. Indeed, the long expectancy condition will allow a very long block of trials over which a slow-developing practice effect could be seen, if anticipations are rather automatic and hard to bring under cognitive control without a very large amount of experience. However, data from fixations masked with short SODs will still be obtained (though less frequently than in the random condition with equal probabilities). It was believed that this would provide data which might allow a differentiation between preprogramming and direct control as an explanation for fewer anticipations.

Even when anticipation saccades occur, it is not necessarily the case that no information is gained in the fixation. Although there is no information in the area occupied by the mask, some may be gleaned from the region surrounding the mask. Mask size then, might affect the likelihood of anticipations in various ways. Very small masks, allowing more valid information processing in spite of the mask may cause the subject to move along with rather normal fixation durations, reading out of parafoveal vision. Large masks perhaps leave the reader no choice but to wait out the mask, since little information can be gleaned from beyond the mask. If mask size has an effect on anticipations, it also could be used to differentiate direct control

and preprogramming. Rayner and Pollatsek masked either the central seven characters, the central seventeen characters, or the entire line. It appears that there were differences in saccade size of the anticipation eye movements due to mask size (see their Figure 2), though paradoxically the saccades were shorter with larger masks, implying anticipations do not simply saccade out to the edge of the mask. As already mentioned, some of the anticipations may actually have been drifts of less than one character. This may be affecting the saccade lengths Rayner and Pollatsek reported, especially if the proportion of anticipations was changing with mask size.

Rayner and Pollatsek only manipulated the mask size in fixed blocks. The present experiment varied mask size randomly from fixation to fixation in order to see if saccade length of the anticipations are determined on an immediate basis. Though Rayner and Pollatsek found evidence for direct control when they varied the size of a window randomly from fixation to fixation, they concluded that the anticipations found with stimulus onset delays might not be due to the same source of eye control. If anticipations are preprogrammed they should not be sensitive to mask size when varied randomly, as regular saccades are expected to. Mask size serves as a converging operation to further discriminate direct and preprogramming models of eye movement control for the anticipations.

To summarize, the experiment here described varied mask size randomly while mask duration was manipulated in a variety of ways. It remained fixed over a block of trials or varied randomly with various

probabilities of different durations. An examination of the fixation durations, especially those lasting less than the duration of the mask, was planned in order to differentiate between immediate, direct control and delayed control or preprogramming of eye movements in reading.

C H A P T E R I I

METHOD

Subjects

Twelve University of Massachusetts students read passages of text while their eye movements were recorded in return for course credit or money. All were naive subjects and for most this was their initial exposure to eye tracking experiments. All had normal uncorrected vision and English was their native language.

Apparatus

A Hewlett-Packard 2100A computer controlled the presentation of stimuli on a CRT (H-P 1300A X-Y Display) and received an eye position signal on-line from a Stanford Research Institute Dual Purkinje Image Eyetracker (Clark, 1975; Cornsweet & Crane, 1973). The equipment monitored the right eye; viewing was binocular at a distance of approximately 54 cm. The computer algorithm which scored the eye position signal required that fixations last for 100 msec in order to be acknowledged. The computer responded to various toggle switches operated by the experimenter. These ran a calibration program and presented sentences. For further details of the calibration procedure and eye monitoring algorithm see Rayner, Inhoff, Morrison, Slowiaczek,

and Bertera (1981). The letters were composed of dots in a five by seven matrix with three character spaces filling approximately one degree of visual angle, in width. A response key pressed by the subject indicated that each stimulus had been read.

Stimuli

Twenty simple stories were read for comprehension. The stories were interesting and amusing real-life vignettes adapted with minor modifications from a larger source compiled by the late broadcast journalist Lowell Thomas (Thomas, 1940). The stories were presented one line at a time and were all 16 lines long with 30 to 42 characters on a line. Each line ended with punctuation: a sentence-ending period or exclamation point, or a comma, dash, colon, or semi-colon occurring at a natural point in the text. For each story a multiple choice comprehension question was written. There was also one practice story and comprehension question. The stories and questions are presented in Appendix B and Appendix C, respectively.

The choice of stimulus materials consisting of connected text was made on methodological as well as theoretical grounds. It was thought that providing contextually rich and interesting information would (1) keep subjects motivated and alert, and (2) encourage them to attend to the text and guide their eyes to seek information (i.e., to read) rather than introspect about their eye behavior while simply fixating and encoding words. In turn, this would lead to better eye tracking, including fewer track losses, and ecological validity. Furthermore,

the comprehension questions not only encouraged deep processing of the stories and served to disguise the theoretical reasons for the experimental manipulation, but also allowed a check on performance across all conditions to see whether subjects were in fact reading for meaning.

Procedure

Upon arrival for the experiment, subjects were briefed on the operation of the laboratory equipment and general procedure to be followed and given a sheet of written instructions pertaining to the experiment. After soliciting informed consent, a bite bar was made in Kerr dental impression compound to eliminate head movements during the experiment. Following alignment and calibration of the eye tracking system the subject read some text for practice. The text reviewed the instructions, which told the subject to press a response key after having read each line in order to prompt the following line (after a very brief lag). The instructions also said to read naturally for comprehension and to ignore any perturbations of the display which would occur during the course of the experiment. Subjects were told there would be four blocks of five stories each, with a break between blocks during which time they would take a pencil and paper comprehension quiz on the preceeding group of five stories. A practice story was read and a practice comprehension question presented orally before beginning the experiment proper.

Experimental design

During reading of the experimental passages, the text was manipulated contingent upon the reader's eye position. Specifically, at the onset of each eye fixation either a 5 or 15 character mask (composed of an inverse-contrast square-wave grating) was displayed for a period of 350, 200, 50, 25, or zero milliseconds, the latter being a no-mask control condition. Thus the presentation of the nominal stimulus was delayed within the central 5 or 15 character spaces with respect to the reader's point of regard. The spatial extent of the mask varied randomly from fixation to fixation in all conditions. The temporal extent of mask, or stimulus onset delay, was manipulated across 4 sets of 80 sentences (5 consecutive stories) which comprised the experiment.

In the blocked delay condition the delay was held constant for an entire 16 line story, and changed only between stories. In the random-equal condition the delay varied randomly from fixation to fixation with an equal chance of a long (200 or 350 msec) or a short (0, 25, or 50 msec) delay on a given fixation, for all 80 sentences. In the random-long expectancy condition the delay on a given fixation was again determined by a chance process, but with a greater probability of a long delay occurring than a short delay. The probabilities were set at $p(\text{long}) = .8$ and $p(\text{short}) = .2$, again stationary over the entire set of 80 sentences. In the random-short expectancy condition the delay varied randomly with the bias in the opposite direction, favoring short delays ($p = .8$) over long ($p = .2$).

One half of the subjects received the blocked delay condition on the first set of stories, the other half on the last set of stories. The three variable conditions were administered all in a row with order counterbalanced. In the blocked delay condition the zero-delay control occurred on either the first, third, or last passage of the set and the order of the four non-zero delays among the remaining four passages was balanced using a Latin-square procedure. The order of the four sets of stimuli was also counterbalanced across the four manipulations of stimulus onset delay.

C H A P T E R I I I
RESULTS AND DISCUSSION

Reading Comprehension

Scores on the comprehension questions indicated that subjects were reading for meaning in all conditions (Table 1). If anything, performance improved when central vision was masked for long periods. This justifies the assumption that the observed eye behavior reflects changes necessary in order to maintain the cognitive processing necessary for skilled reading when confronted with the experimental manipulations.

Table 1
Comprehension scores (proportion correct) achieved
at each condition of SOD manipulation.

SOD Manipulation	Stimulus Onset Delay (msec)					Total
	0	25	50	200	350	
Blocked	.58	.50	.66	.66	.66	.61
Random - Equal	-	-	-	-	-	.66
Random - Long	-	-	-	-	-	.68
Random - Short	-	-	-	-	-	.60

Note: Since questions followed entire blocks of stimuli, data for individual SODs are unavailable in the random conditions.

Fixation Duration

Global analysis. Figure 1 shows average fixation duration increasing with stimulus onset delay, almost identically for conditions in which the delay was held constant or varied randomly from fixation to fixation with equal likelihood of a short or a long delay. Means for the entirety of fixation durations, and means disregarding anticipations (the solid and dashed curves, respectively) have been plotted. The data are broken down by mask size which exerted a more powerful influence on fixation duration than the expectancy resulting from SOD manipulation. Data from the random SOD manipulations with long and short expectancies exhibit nearly identical data as that in Figure 1 but are not included in the interest of clarity. Table 4 in Appendix A presents the data for all conditions. Since some of the values in the long and short expectancy conditions were based on very few observations per subject, the following statistical tests refer to data from the random-equal and blocked conditions only.

Considering the solid curves of Figure 1, it is clear that as display of the text in central vision is delayed, the average fixation duration increases, $F(4,44) = 78.0$, $p < .001$. The overall mean fixation duration at the zero delay was 241 msec. This increased to 262 msec at the 25 msec SOD, 276 msec at SOD-50, 321 msec at SOD-200, and 337 msec at SOD-350. While mean fixation duration increased with stimulus onset delay, the increase was not commensurate. The regression lines predicting mean fixation duration from stimulus onset delay have slopes of .184 and .310 for the 5 and 15 character masks,

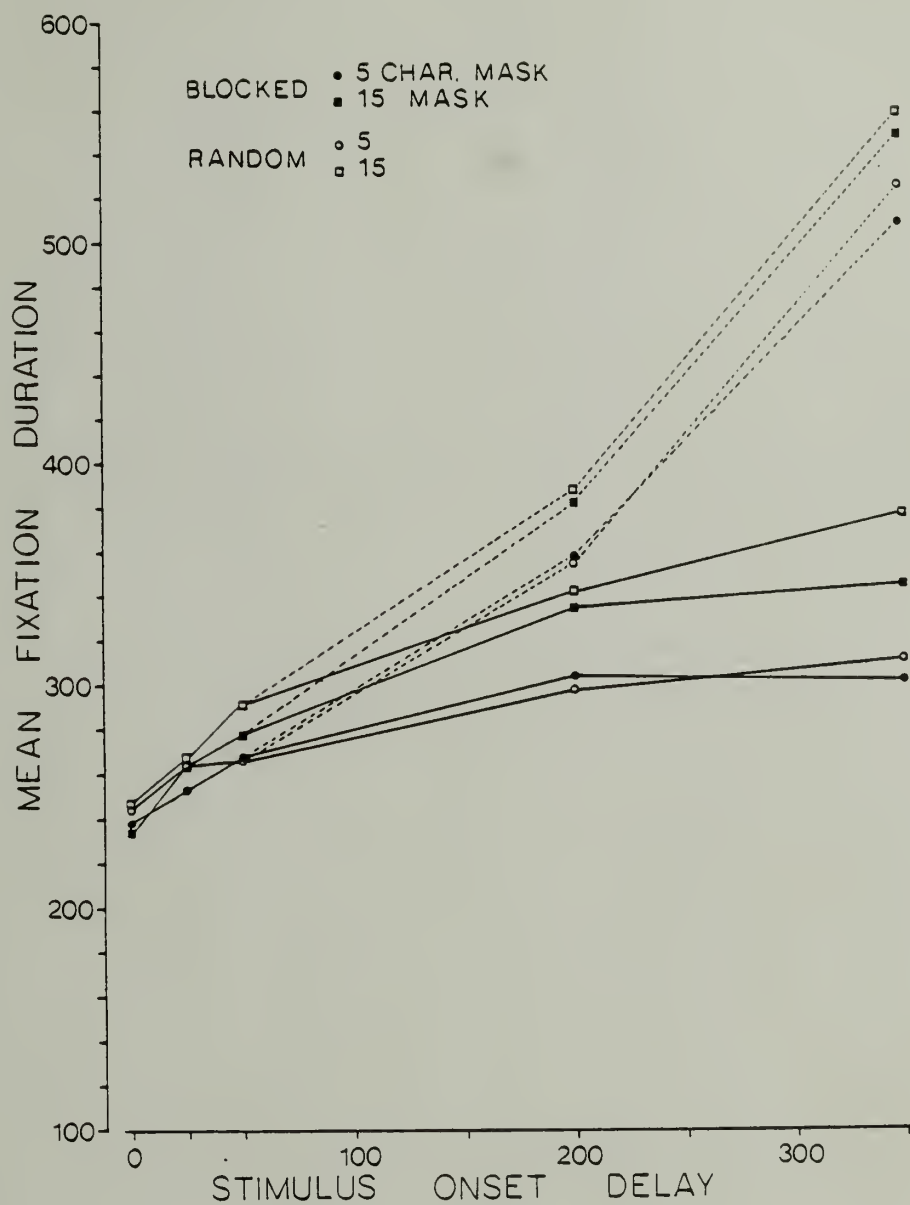


Fig. 1. Mean fixation duration (in msec) as a function of stimulus onset delay and mask size in the blocked and random-equal conditions. (Solid curves include all data, dashed represent data with anticipations removed.)

respectively, in the blocked condition, and .184 and .363 for the 5 and 15 character masks in the randomized condition (r squared greater than .81 in all cases). Thus, masking the central 15 characters increased fixation duration to a greater degree than masking only 5 characters. When collapsed over all delays (including the "zero" delay which actually had no mask), fixation duration averaged 299 msec for the 15 character mask and 276 msec for the 5 character mask, yielding a main effect of mask size $F(1,11) = 77.5, p < .001$.

The main effects of delay and mask size simply indicate that preventing a portion of the stimulus from being seen increases the average fixation duration in proportion to the temporal and spatial metrics of the mask. That is, prolonged masks cause longer fixations and larger masks cause longer fixations. In addition, masking the larger span of letters was more detrimental the longer this situation persisted, amplifying the increases in fixation duration. For instance, the difference in fixation duration between the two mask sizes was 56 msec at SOD-350 but only 7 msec at SOD-25. This trend is indexed by the interaction of Delay and Mask Size, $F(4,44) = 28.5, p < .001$.

The blocked zero delay condition was a "true" control condition in which subjects read freely, unhampered by eye contingent display changes of any type and it had the shortest average fixation duration, 236 msec. Fixation durations were 10 msec longer in the randomized condition at zero delay - 246 msec - and perhaps represent the more appropriate baseline against which to judge effects of stimulus onset

delay, as eye contingent display changes may have generalized effects on processing efficacy in addition to the specific effects of the stimulus onset delay during individual fixations. In fact, the difference in mean fixation duration between the two SOD manipulations is less than 10 msec at three of the four remaining SODs. Including even the zero delay data the overall effect on fixation duration across all delays is only an additional 9 msec for the randomized presentation versus the blocked. Therefore, whether the temporal extent of the masks varied randomly from fixation to fixation or remained constant throughout a block of stimuli did not produce a significant effect, $F(1,11) = 3.3$, $p = .094$. This suggests that the increases in fixation duration were mediated immediately and directly by the stimulus onset delay as opposed to preprogramming of fixation duration, since delay could not be predicted in the randomized condition. The interaction of Mask Size and SOD Manipulation, $F(1,11) = 7.2$, $p < .05$, indicated a larger effect of mask size in the randomized SOD condition (a 28 msec difference versus only 19 msec in the blocked condition).

At the long delay intervals many fixations were actually terminated before the masking interval had completed, negating any glimpse of the masked text. It had been predicted that these anticipation eye movements would be suppressed in the blocked condition, resulting in longer fixation durations on average than in the randomized condition, especially at the 200 and 350 msec delays. This clearly was not the case. As noted above, the SOD manipulation had no significant main effect, nor was there any interaction with

delay, $F(4,44) = 1.02$, $p = .41$.

When anticipation responses are removed from the data (the dashed branch of curves in Figure 1) the increases in mean fixation duration with stimulus onset delay are more nearly equal. For these data the overall mean fixation durations at SOD-200 and SOD-350 are 373 msec and 541 msec, respectively. As before, there are highly significant main effects of delay ($F(4,44) = 1,116.0$, $p < .001$) and mask size ($F(1,11) = 40.4$, $p < .001$), and a Delay by Mask Size interaction ($F(4,44) = 8.2$, $p < .001$). Now the slopes of the regression lines predicting mean fixation duration from SOD are .769 and .879 for 5 and 15 character masks, respectively, in the blocked condition, and .792 and .878 for the 5 and 15 character masks, respectively, in the randomized condition (r squared greater than .96 in all cases). The main effect of SOD manipulation for these data just reaches significance at the 5 percent level ($F(1,11) = 5.2$, $p = .042$). Overall, fixation durations were slightly shorter in the blocked condition, by precisely the same amount found for the entire data set - 9 msec, but the error term for the F-ratio was smaller. It may be that there is a slight advantage when the SOD is predictable, but this is not associated with the expected impact of the blocked presentation - a reduction in anticipations. The much larger error term for the complete data set seems to indicate that including the anticipations in a blocked versus random comparison just adds noise.

Interestingly, with the anticipations removed the SOD Manipulation by Mask Size interaction disappears ($F < 1$) suggesting that the effect

was due to the anticipations. Thus, either the duration or proportion of anticipations must have been differentially affected by mask size in the blocked and random conditions. This finding will be returned to below. The fact that slopes for predicting fixation duration from SOD now approach positive one argues persuasively for the notion that fixation duration, or equivalently the timing of the next saccade, is controlled directly within a given fixation subsequent to encoding the stimulus. However, the anticipation eye movements are not consistent with a strict interpretation of direct control. Since the anticipations were not reduced under blocked presentation as Vaughan had found (1978, p. 139), they do not appear to be consistent with a model of eye movement preprogramming either.

The lack of a reduction in anticipation eye movements from the random-equal to the blocked condition is seen graphically in Figure 2. (Table 5 in Appendix A presents the data for all conditions.) Even though the only way to view text in the fovea was by temporally extending the fixation until the delay was over, there were actually more anticipation eye movements under blocked than under random presentation (46% versus 43%), although this difference was not significant ($F(1,11) = 1.65, p = .22$). As can be clearly seen, the longer the mask lasted the higher the likelihood the eye moved while the mask was still present (65% at SOD-350 versus 24% at SOD-200), $F(1,11) = 725.7, p < .001$. Interestingly, anticipation eye movements were also more likely for the smaller mask size (50% versus 40%), $F(1,11) = 66.7, p < .001$. Since mask size varied randomly throughout

the entire experiment, this demonstrates a direct influence of the stimulus seen in the fixation pause immediately preceding an anticipation eye movement, contrary to preprogramming in its purest form.

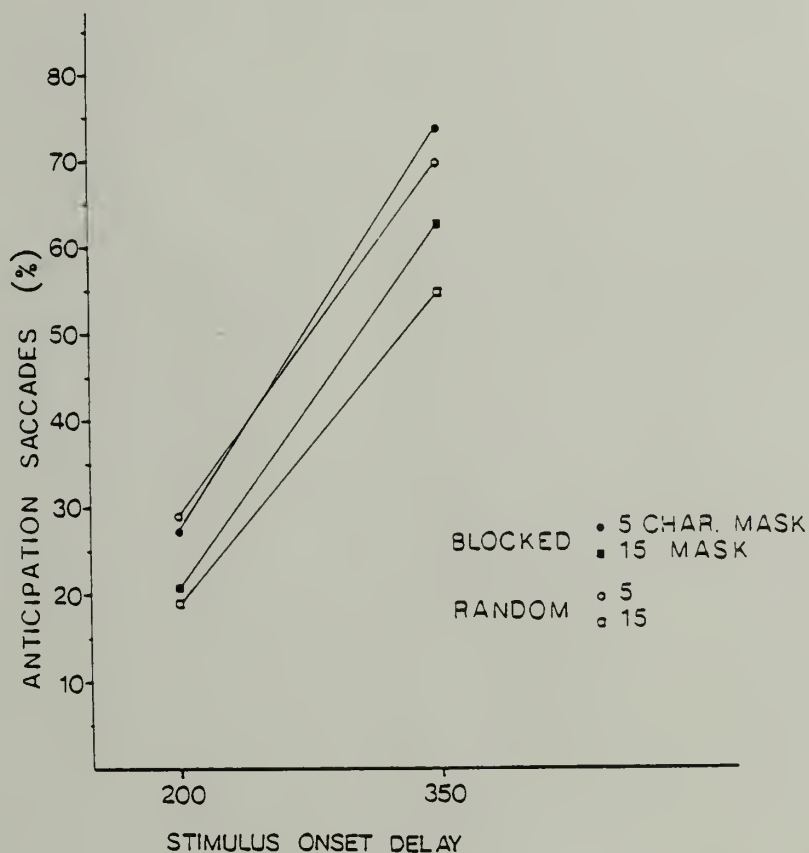


Fig. 2. Percent anticipations (fixations less than the SOD) as a function of stimulus onset delay and mask size.

Although in general the proportion of anticipation eye movements on 15 character masks was attenuated in comparison to 5 character masks, this was less so in the blocked SOD manipulation (a decrease in

percent anticipations of 8 as opposed to 12), $F(1,11) = 5.1$, $p < .05$. This accounts for the interaction of SOD Manipulation and Mask Size on total mean fixation duration - a change in the proportion of anticipations will cause a corresponding change in the mean fixation duration functions. Also, since the somewhat greater tendency to make anticipation eye movements under blocked presentation accrued solely at the 350 msec stimulus onset delay (an additional 6% anticipations versus no difference at SOD-200), there was a significant Delay by SOD Manipulation interaction, $F(1,11) = 5.9$, $p < .05$. Taken together, the two findings that blocked presentation leads to more anticipations than random at SOD-350 and with 15 character masks, indicate that anticipation eye movements are encouraged under more difficult circumstances by the blocked presentation. This suggests that in the situation where a sizable region of central vision was masked consistently for an interminably long period readers were not trying to wait out the mask much of the time but instead were attempting to extract information directly from extrafoveal vision. Obviously readers did not adapt ocular behavior to wait out the 350 msec SOD on each fixation. Perhaps they opted to first attempt to decode information from the region outside the mask, reading out of extrafoveal vision. This would not be as powerful as reading with the aid of foveal input and would therefore require more fixations. Figure 3 provides evidence that this is indeed the case. The total number of fixations per line increased when central vision was masked for 200 and 350 msec. Interestingly, if anticipations are not counted the number

of fixations (i.e., those on which foveal processing took place) actually decreased by over 50% at the 350 msec delay. The decreased incidence of foveal processing means that the fixations preceding anticipatory saccades were contributing semantic information, though not as efficiently as fixations including foveal processing. In light

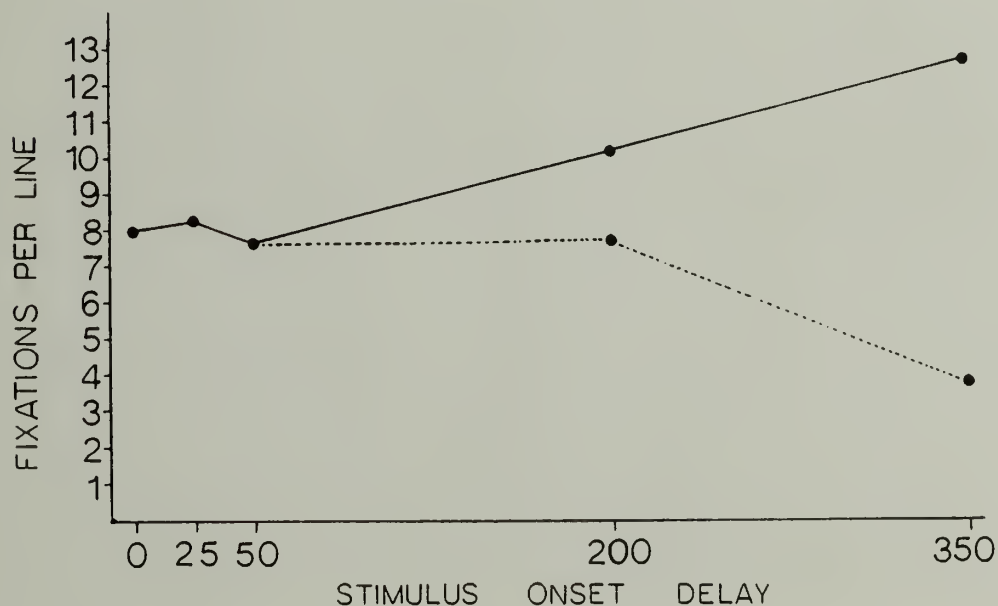


Fig. 3. Number of fixations per line of text as a function of stimulus onset delay in the blocked condition. (Solid curve includes all fixations, dashed curve represents data with anticipations removed.)

of the similarity between the random SOD condition and the blocked condition, it would appear that the same process accounts for anticipations in the random conditions as well. If so, reading out of extrafoveal vision may occur on many fixations in normal reading, not

only as an aberrant strategy induced by the constant presence of long lasting masks in central vision. Perhaps anticipations are responses on which information is sought mainly from extrafoveal vision, not from the foveal region.

The average fixation duration on anticipation responses was around 150 msec on the 200 msec delay and about 225 msec at the 350 msec delay. This means that many of these fixations lasted less than 150 msec, the estimate of the minimal oculomotor latency. If 150 msec is the correct estimate of minimal latency, the anticipation saccades interrupting fixations at durations less than 150 msec were quite likely elicited by events occurring prior to the fixation that preceded them. Since these were found at long delays in a randomized condition, they must logically occur at the shorter delays too. However they would still outlast the mask duration and they would not be coded as anticipations. Many fixation durations at short delays are less than 150 msec and we must ask whether these are not the same as the anticipations found at long delays. Perhaps at short delays a good number of fixations are not influenced by factors in the immediately preceding fixation, which in the present paradigm would mean not elongated by the delay of the text in central vision. Therefore, a more detailed analysis of fixation duration was undertaken.

Local analysis. Individual data from four subjects in the random-equal condition was analyzed (see Figure 4) in order to ascertain whether the distribution of fixation durations at short delays is simply shifted upward from the zero delay case, or, if only a proportion of fixation

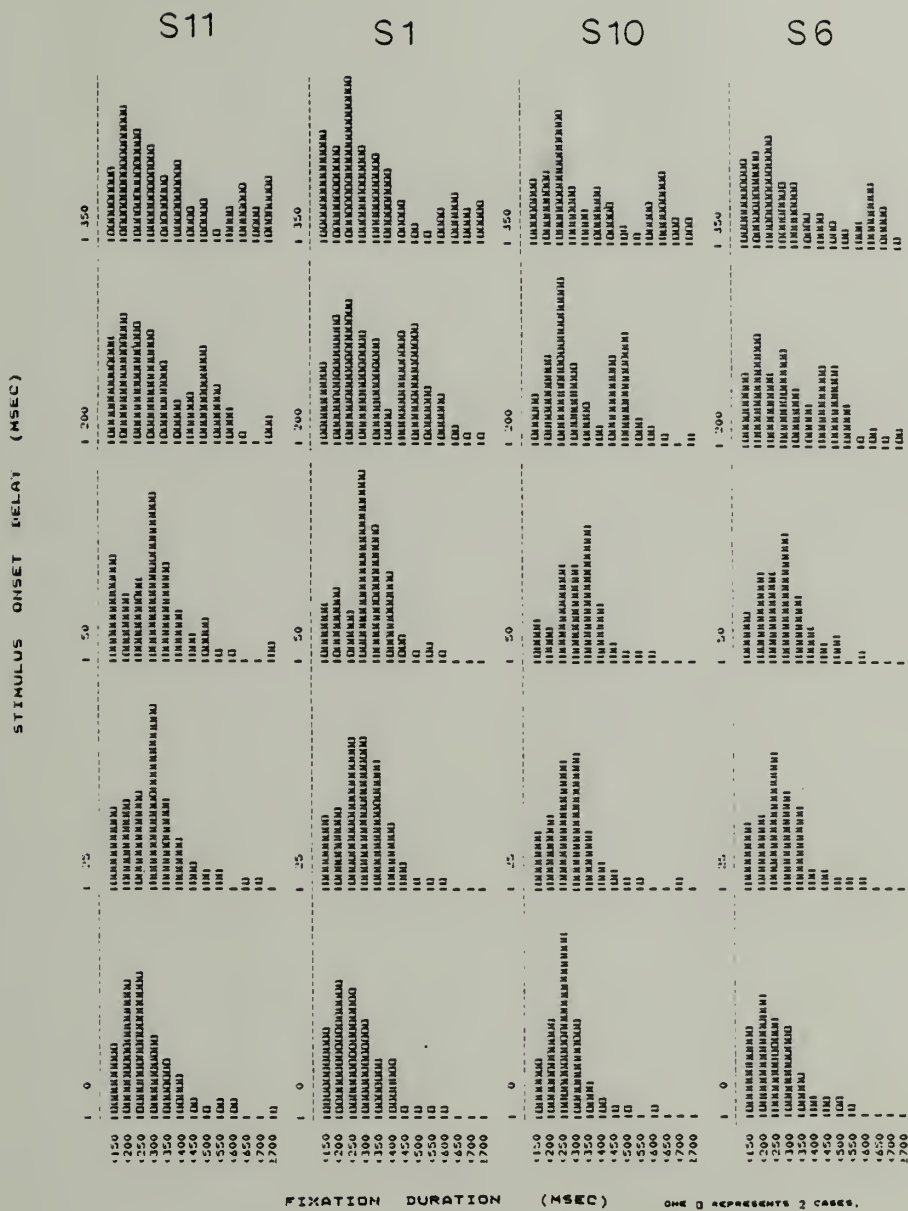


Fig. 4. Histograms of fixation duration (in msec) at each stimulus onset delay in the random-equal condition. (Individual data of four subjects.)

durations are lengthened, resulting in a more variable and possibly bimodal distribution. The four subjects were chosen on the basis of agreement (by eye) of their mean fixation duration versus SOD functions with the group trend. Thus, the four subjects all demonstrated curves that increased monotonically with a fairly even slope, especially at the zero, 25, and 50 msec delays. The distributions are clearly bimodal at the 200 and 350 msec delays and in some cases at the 50 msec delay. At the short delays it does appear that two kinds of fixation durations contribute to the distribution: very short ones less than 150 or 200 msec which do not appear to shift upwards in response to the presence of the mask, and longer ones that are lengthened, though increasing by more than the amount of the delay - 50 to 100 msec instead of 25 or 50 msec.

Rayner and Pollatsek pointed out that some of the anticipation eye movements they observed were small movements of one character or less and perhaps represent "noise" in the system if it is difficult to hold the eyes still for so long. Perhaps these account largely for the short duration fixations which are not affected by the SOD. Figure 5 is a representation of the data from Figure 4 differentiated with respect to saccade length. Responses were divided into 2 classes; those followed by an eye movement (either forward or regressive) of 2 or more characters, and those followed by movements of 1 character or less. The 1 character saccades accounted for only about 10% of all eye movements and were distributed fairly evenly across the range of fixation durations. Specifically, they did not account for all the

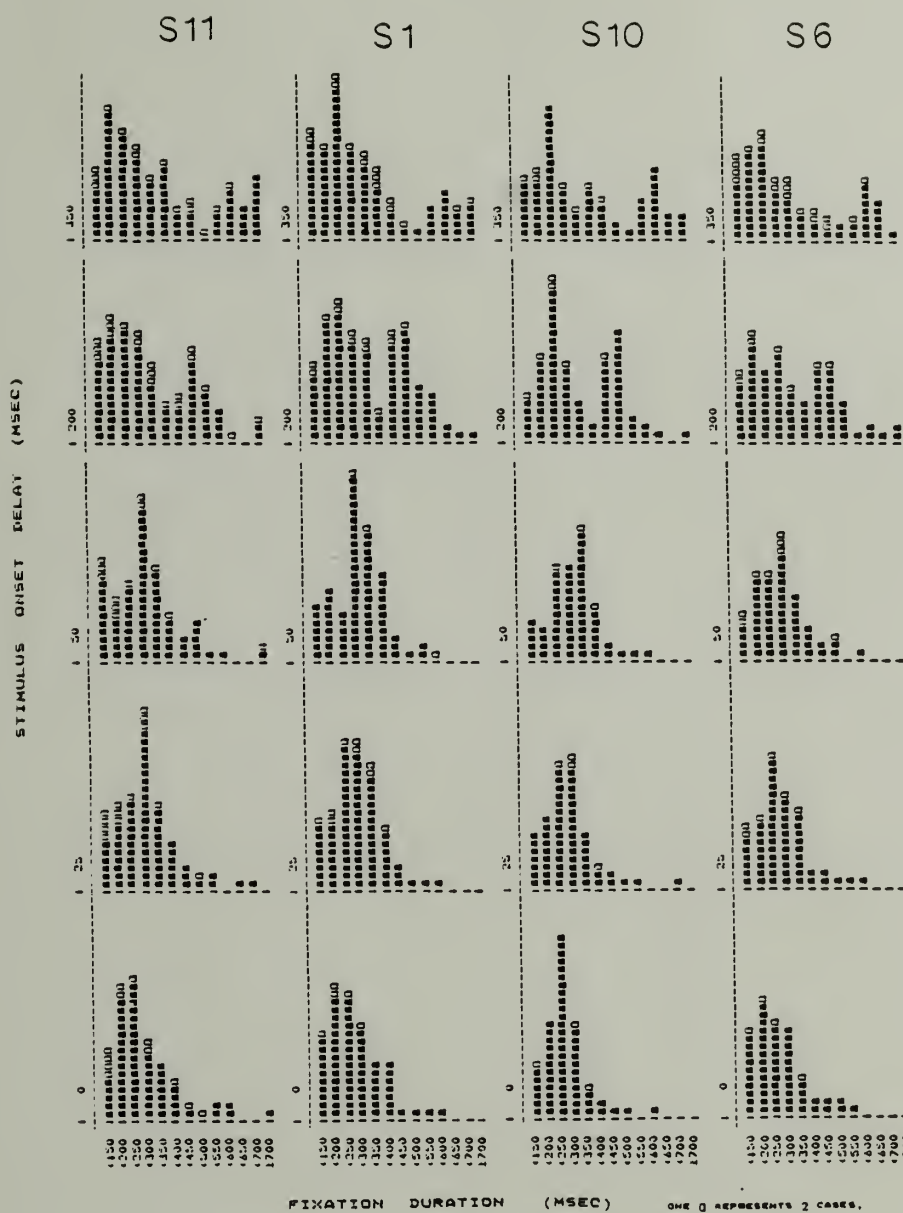


Fig. 5. Fixation duration histograms showing size of following saccade. (Filled rectangles = eye movement of two characters or more, open = one character or less. Individual data of four subjects.)

brief fixations and were not the reason for the bimodality and skew seen at any of the SODs, short or long. The majority of the very brief fixations were followed by saccades of typical length. Of course, whether or not the 1 character eye movements commonly observed in reading represent "oculomotor noise" is a good question (McConkie, 1983). They may reflect attentional processes. In any event, the apparent dual process determination of fixation duration cannot be explained by either a noisy system or as tiny attentional shifts around essentially the same point in the visual field.

As noted earlier, there were significantly more anticipations when a 5 character mask was displayed than a 15 character mask (50% vs. 40%). This trend can be seen for the SOD-200 and SOD-350 data in Figure 6 where the individual fixation duration histograms are differentiated with respect to mask size. At the shorter SODs also, it appears that the fixations which are greatly inflated by the SOD are more often than not those on which a 15 character mask was displayed, while the shortest fixations seem to be comprised more of those receiving a 5 character mask. Though unintuitive, this finding would be explained if some aspect of the target for an anticipation eye movement is often between 3 and 7 characters from the fixation point and is therefore obliterated by the large mask but not the small one. A partially programmed eye movement would not be disrupted by the 5 character mask, so it would complete programming of the movement needed to foveate the target and then execute it. But the 15 character mask would obscure the target and disrupt the programming of the saccade.

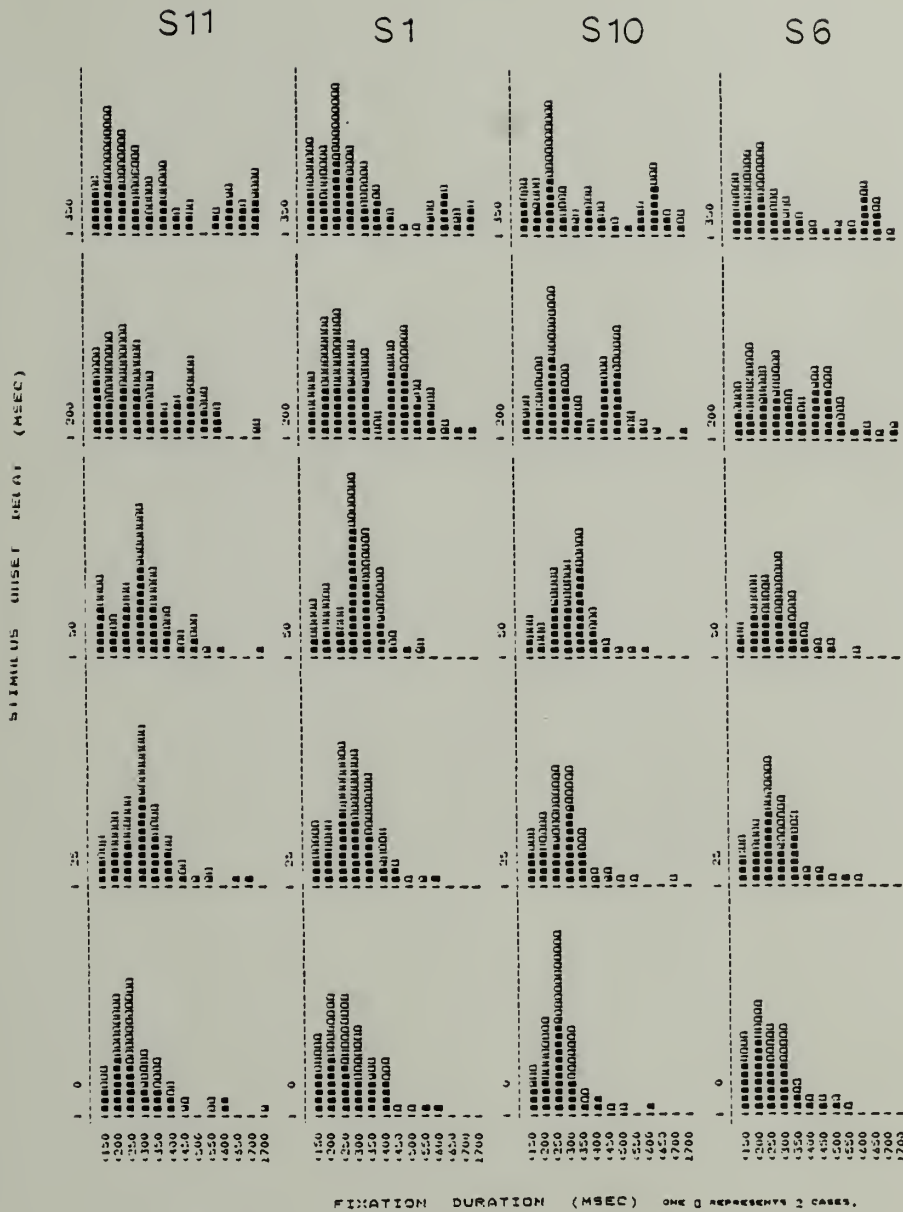


Fig. 6. Fixation duration histograms showing size of the mask. (Filled rectangles = 15 character mask, open = 5 character mask. Individual data of four subjects.)

The eye might still move but after a longer latency because of the disruption, or it might cancel the response completely and wait for the mask to disappear. If the target the anticipations are aimed at is the next word to the right of fixation, then the most important information for determining its location is the immediately preceding space (Pollatsek & Rayner, 1982) which would often lie between 3 to 7 characters to the right of the fixation point. The fact that many anticipations are about 5 characters in length agrees with this hypothesis.

The average first, second, and third quartiles at each SOD and mask size for the same four subjects are shown in Figure 7, as well as the average of their mean fixation durations (significance tests are summarized in Table 2). Here it can be seen that all portions of the distribution of fixation durations do not behave in a manner similar to the mean fixation duration. The lowest quartile of fixation durations does not shift upward in proportion to the SOD as the upper portion of the distribution does. For instance, the regression lines predicting mean fixation duration from stimulus onset delay, for the 5 and 15 character masks, are .191 and .367, respectively, for these four subjects (similar to the values of .184 and .363 based on all 12 subjects). Interestingly, the slopes for the third quartile are steeper than those for the mean. They are .316 and .741 on 5 and 15 character masks, respectively. On the other hand, the slopes for the first quartile are -.010 and .169, respectively, much less than the mean, and only .030 and .264 for the median.

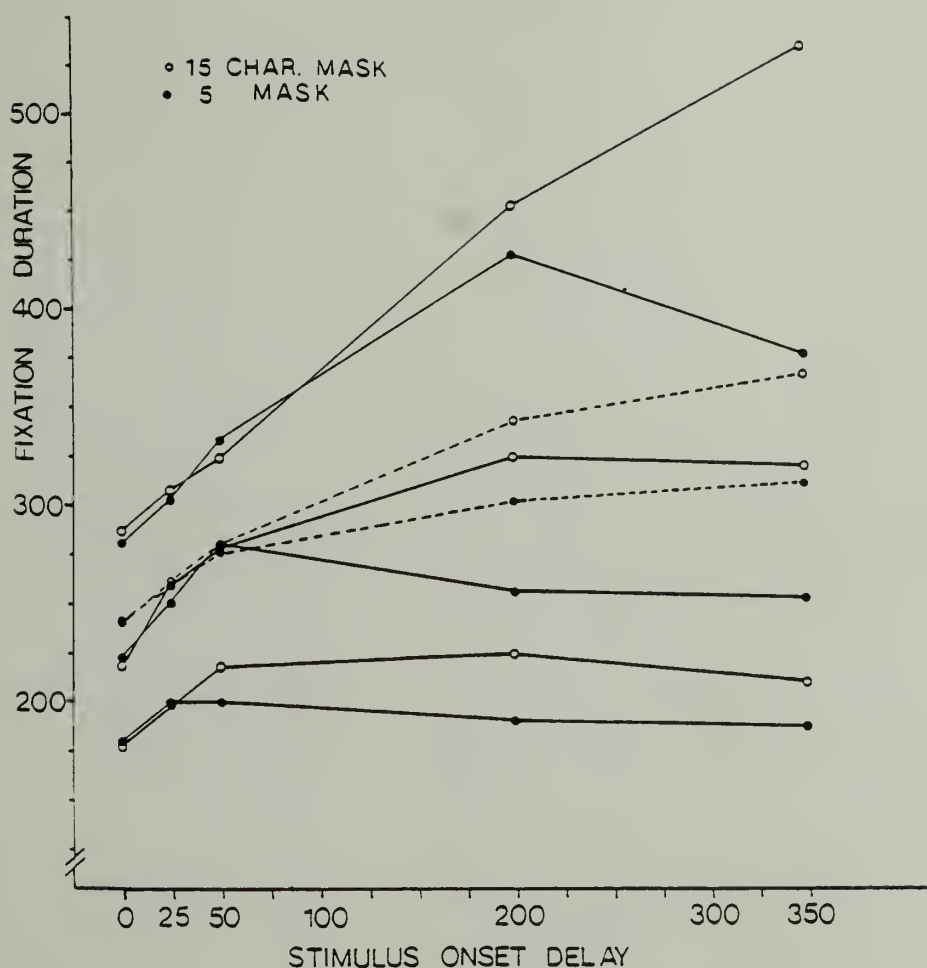


Fig. 7. Mean fixation duration (dashed line) and quartile fixation durations (25th, 50th, and 75th percentiles, from bottom to top, respectively) as a function of stimulus onset delay and mask size in the random-equal condition. (Averages of four subjects.)

Indeed, apart from a difference between the zero delay (where no mask occurred at all) and the other delays the first quartile does not increase with SOD for the 5 character mask. It is inferred that there

may be a general disruptive effect due to the mask as it displaces the pattern that had been in parafoveal vision before the saccade, hindering integration of information across the successive fixations (Rayner, McConkie, & Ehrlich, 1978). Thus an increase of about 20 msec may occur on any fixation which actually involves text mutilation, be it for 25, 50, 200, or 350 msec. The critical question is whether the durations of the fixations show a near linear increase with the time the mutilation is present. This appears to be true only for some data.

Table 2

F-ratios from ANOVAS on data in Figure 7.

Dependent Measure	Effect (df)		
	SOD (4,12)	Mask (1,3)	SOD x Mask (4,12)
75th percentile	33.9 **	38.5 *	24.3 **
50th percentile	10.2 **	19.9 *	9.9 **
25th percentile	6.2 **	3.8	1.3
mean	62.0 **	110.0 **	8.4 **

* $p < .05$

** $p < .01$

Disregarding the zero delay values, and analyzing only the fixations from conditions actually involving text mutilation reveals no significant main effect of SOD on median fixation duration, $F(3,9) = 2.4$, $p = .13$, or fixation duration of the 25th percentile, $F < 1$. The effect is still very strong for the 75th percentile though, $F(3,9) =$

26.7, $p < .001$, and for the mean, $F(3,9) = 42.3$, $p < .001$. Apparently the SODs lengthen the duration of only some fixations, not all. Consequently the distribution is stretched out as seen in the histograms of Figure 4 - 6. Short fixation durations are not upwardly displaced very much, while longer ones are displaced by an amount actually greater than the duration of the mask. The weighted mean of these classes of responses can spuriously result in a fixation duration versus SOD function which increases with a slope of nearly positive one, suggesting a single underlying phenomenon. Even looking only at data from the short delays, where all the data fall nearly on straight lines, we see an inequality of the slopes. The slopes predicting mean fixation duration on the 5 and 15 character masks are .705 and .810, respectively. However, the slopes for median fixation duration are 1.17 and 1.19, and the slopes for the 25th percentile are only .405 and the .825, respectively. (1.06 and .760 for the 75th percentile.)

Since anticipations were more likely on a 5 character mask, somewhat longer fixations were more likely on a 15 character mask, resulting in main effects of mask size (see Table 2). The effect was weak and failed to reach significance at the 25th percentile because only a few of these fixations were affected at all by the SOD, as argued above. Figure 7 also shows for each dependent measure that the mask size effect occurs only at SODs longer than a certain value, resulting in an interaction of SOD and Mask Size. Just where the curves separate depends upon the length of the fixation durations in question. The explanation seems to be that the longer the SOD lasts,

the more likely it is that the mask will still be present while the next eye movement is programmed. If the mask is still present, programming for saccades will be disrupted to a greater degree or completely aborted by 15 character masks, raising fixation durations. Since short SODs will usually allow the mask to be over by the time the eye movement is planned, mask size will be irrelevant at that point as far as influencing when the saccade occurs. With longer fixation durations the saccadic decision occurs later, thus a longer SOD can occur and still be over by the time the saccade is programmed. Therefore the curves separate later for the 75th percentile than the 50th, which in turn divides later than the 25th percentile.

If we assume that the last stimulus event which can influence the very next saccade must occur at least 150 msec or so before the end of a fixation (this includes 50 - 60 msec for a stimulus to arrive at the cortex before the initiation of programming and efferent transmission stages totaling about 100 msec), then the explanation is perfectly consistent with the data. Where the fixation duration minus the SOD is less than about 150 - 175 msec, the curves are distinct, as would be expected since the mask would still be perceived when eye movement decisions were made. If this value is greater than about 175 msec the curves overlap (i.e., there was no mask perceived when the eye movement was planned).

The hypothesis that is emerging to explain how the mask interacts with eye movement control is the following. How long a fixation lasts before processing is completed to some level and the next saccade is

called for is highly variable. If a mask is perceived when this state is reached the saccade will be made contingent upon the mask. The decision to move the eye is more likely to be postponed if the mask extends 7 characters to the right of the fixation point than if it only extends 2 characters, as the larger mask is more likely to obscure the word boundaries to the immediate right of fixation. The data suggests that a stimulus event which reaches central structures 100 msec or so before a fixation ends may affect the decision. This suggests that an eye movement program is committed to about 100 msec before the eye actually moves.

Saccade Length

Global analysis. The lateral extent of forward saccades in the blocked and random-equal SOD manipulations, averaged over all 12 subjects, is illustrated in Figure 8. Data for saccades following fixations which did not outlast the SOD are identified separately. The overall mean for these anticipations is 6.1 character spaces, the same as for saccades not classified as anticipations. This is quite different than the pattern observed by Rayner and Pollatsek (1981), who found anticipations which were appreciably shorter (about 4 characters or less) than the "regular" saccades (averaging 6 characters or more). The Rayner and Pollatsek results included a condition with a full-line mask, in contrast to the present data.

An analysis of variance on lengths of saccades which were not anticipations revealed a highly significant main effect of SOD

manipulation ($F(1,11) = 12.9, p < .001$) due to longer saccades in the blocked condition on average (6.3 characters) than in the random-equal condition (6.0 characters). Mask size did not affect mean saccade length (6.1 characters on both mask sizes, $F < 1$). The most parsimonious interpretation to draw from these data is that mask size had little or no effect because for the most part the mask were gone by the time these saccades were programmed.

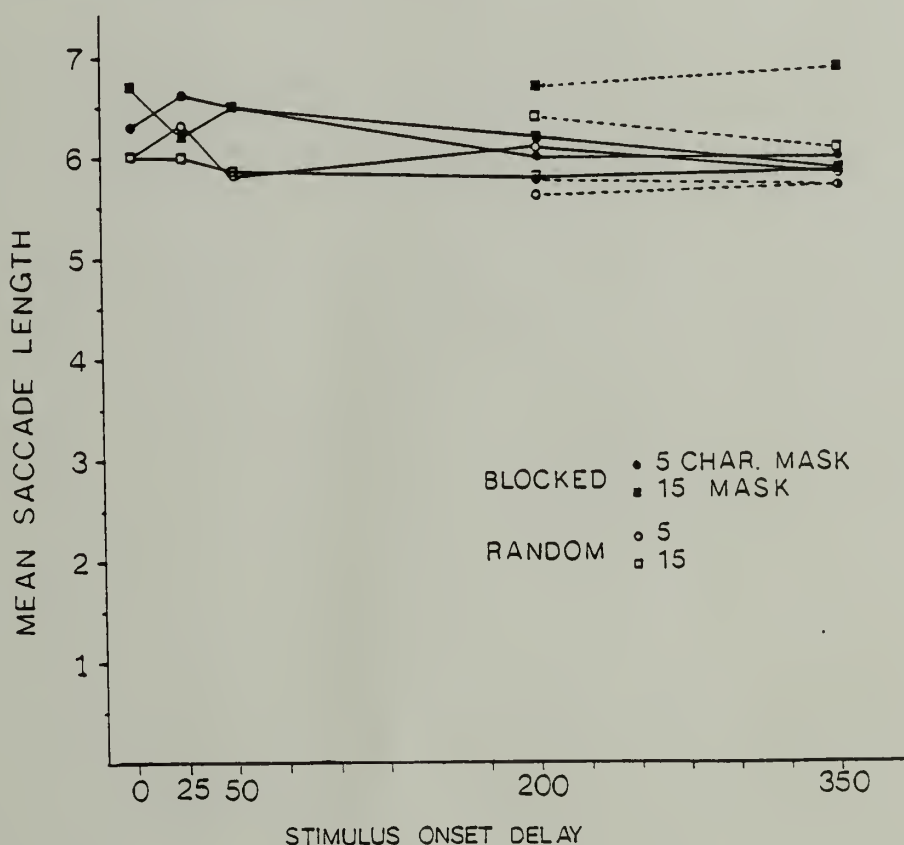


Fig. 8. Mean forward saccade length (in characters) as a function of SOD and mask size in the blocked and random-equal conditions. (Solid curves = saccades following fixations longer than the SOD, dashed = anticipations.)

Although mean saccade length appeared to decline rather steadily as stimulus onset delay increased, the trend was not significant, $F(4,44) = 1.5$, $p = .23$) perhaps because of a large degree of variability in the measure relative to the size of the effect. If there was a degradation due to long SODs, it would suggest that the reason the blocked condition produced longer saccades was because on short SOD blocks each fixation received only a short delay (a short delay in the variable condition could have been preceded by a long delay), and predicts therefore an interaction between SOD and SOD Manipulation. Indeed, the difference between the blocked and random conditions was greatest at the 3 short delays and smaller at the 2 long delays, but this interaction failed to reach significance ($F(4,44) = 1.3$, $p = .29$).

For anticipation saccades, there was no main effect of SOD manipulation ($F < 1$), but there was a highly significant main effect of mask size ($F(1,11) = 10.7$, $p < .001$), due to a large difference between mean saccade lengths on 5 character masks (5.7 characters) and 15 character masks (6.5 characters). Apparently the programming of these saccades occurred while the mask was still present and was not independent of the spatial extent of the mask.

Local analysis. Saccade length data in the random-equal condition from the four subjects used in the detailed analysis of fixation duration was also examined in detail. Specifically, saccades were divided into three categories: those that were true anticipations, those that lasted less than 150 msec longer than the stimulus onset delay (for the zero

delay this simply means a fixation duration of less than 150 msec), or those lasting more than 150 msec longer than the SOD (see Table 3).

Table 3

Mean forward saccade length (in character spaces) analyzed on the basis of the previous fixation duration (in msec) relative to the duration of the SOD.

Mask	Size	Stimulus Onset Delay (msec)				
		0	25	50	200	350
Fixation duration less than SOD						
	5	-	-	-	5.9	5.6
	15	-	-	-	6.1	6.5
Fixation duration 0 - 150 greater than SOD						
	5	5.5	5.5	6.3	5.7	5.2
	15	5.9	5.1	6.2	6.7	5.1
Fixation duration 150 or more above the SOD						
	5	6.5	6.4	6.0	6.4	6.4
	15	6.0	5.9	5.8	5.5	5.8

Note: Dashes represent cells for which no data exists.

(Averages of four subjects.)

This criterion was based on the evidence from fixation durations that those less than 150 msec longer than the delay had probably begun programming while the mask was still present and are similar to anticipations. (Indeed, Rayner and Pollatsek found that saccades

following fixation durations lasting less than 133 msec longer than the SOD resembled anticipation saccade lengths, which were shorter than those following fixation durations lengthened by the SOD.) The present analysis found no differences in overall saccade length at any SOD, nor was there any effect of mask size (all t-tests non-significant).

C H A P T E R I V

GENERAL DISCUSSION

Current Models are Repudiated by Data

The present findings pose problems for all current models of eye movement control in reading. Since stimulus onset delay raised fixation durations equally when blocked or randomly presented, low level rate control or delayed control models may be summarily dismissed. Immediate and direct control of fixation duration in response to cognitive processing of information acquired during the preceding fixation pause was clearly demonstrated, replicating the findings of Rayner and Pollatsek (1981). At the same time, evidence against this notion of direct control was found. That is, on a sizeable proportion of fixations saccadic initiation appeared to proceed without regard to a preliminary evaluation of information (at least foveal information) in the current fixation. This resulted in rather brief durations for these fixations, sometimes terminating while the text-delaying mask was still present in the case of long stimulus onset delays. These responses are unmistakably at variance with existing direct control theories, and have been referred to as anticipations because they appear to decide prematurely how long the processing of text in central vision will take and when the eye will be ready to move.

The anticipations cannot be dismissed as artifacts due to noise in either the eye tracking equipment or the reader's oculomotor system as most of them are saccades of normal amplitude. Neither can they be discounted as responses peculiar to the artificial situation of eye contingent display mutilation, supposing they represent a directly-controlled but low level reflex of the eye to avoid the foveal mask. Though parsimonious, this explanation is rejected for a number of reasons. First, if such were the case, then occasions when the eye remains still and outlasts a long SOD to view the masked text must represent instances of high level processes overriding the low level response. Such cognitive influences were expected to modulate according to how disruptive the mutilation condition was made via manipulating the likelihood of long stimulus onset delays. Also, the trend was expected to show improvement with practice. Neither effect was observed. The proportion of anticipation eye movements was surprisingly stable whether long SODs were constantly presented in fixed blocks or randomly intermixed with short SODs in various ratios. Even the certainty of a very long SOD did not reduce the probability of an anticipation. Nor did long periods of practice affect the behavior. The fixed blocks of constant SOD were twice as long as those employed by Rayner and Pollatsek, and the long SOD expectancy condition provided a tenfold increase in experience in a similar situation, yet the proportion of anticipations was not reduced.

In addition, saccades which appeared to begin programming before the SOD had expired were found at all SODs, not just the long ones.

These saccades were like anticipations in that their latency was not raised proportionally by the delay of the text by the mask, yet their amplitude was affected by the size of the mask. A thorough analysis of data at the short SODs showed that directly-controlled fixation durations were lengthened by an amount greater than the text delay. Hence, the mask did not simply create a pause - it actively disrupted processing, but only on some fixations. The fixation durations which were not lengthened were only the briefest ones where saccadic initiation began before the mask had been processed centrally. Logically then, anticipations could not be directly-controlled responses attempting to escape the mask. These are saccades which do not wait to see the text or the mask at all before commencing programming. They contradict the serial strategy of initiating eye movements subsequent to first processing the currently fixated text.

Rayner and Pollatsek conceded that earlier direct-control models (Rayner & McConkie, 1976) could not embrace the anticipation phenomenon. They adopted a mixed control model where direct control is the modal response, but under certain circumstances preprogramming occurs. They suggested two such occasions. One was preprogramming a corrective saccade for an expected undershoot on the return sweep. Also, in decoding a long word, a saccade to the end of the word may be planned to gain just a bit more visual information, and since the reader is aware that this will suffice to decode the word, the following saccade to the next word is preprogrammed at the same time. Before any new information is actually in hand, indeed before the first

saccade occurs, eye movement decisions for the second saccade would already be determined (presumably residing in some memory buffer).

It should be noted that neither the present experiment nor Rayner and Pollatsek's presented multiple lines of text, so no return sweeps were needed. This leaves the second explanation to account for the anticipations. Since they were quite numerous (45% of all saccades here for the two long delays combined), it is unlikely that they represent a response appropriate only to special circumstances. I intend to show that anticipations can be understood as a natural output of the eye guidance mechanism in general.

More damaging to the preprogramming explanation is the fact that the anticipation saccades and the fixations not extended by the SOD were not totally predetermined. They were clearly under some degree of direct control as indicated by the length of the saccades (and some effects on fixation duration) in response to randomly varying mask size. This immediate influence rules out the strictest form of preprogramming.

A model is needed which can accommodate this variation in direct control and explain why some fixations wait out the mask while others jump the gun. It is clear that either the preprogramming model or direct control subsequent to an initial evaluation of currently fixated information, or a mixture of these models, is inadequate. This exhausts all currently tenable theories of eye control in reading.

Parallel Versus Serial Programming

In order to develop an adequate model, it may be necessary to examine and reformulate certain pre-theoretical assumptions the current models have been derived from. One such belief is that eye control is serial. That is, the sequence of alternating fixations and saccades observed in eye behavior is presumed to be generated by discrete internal processes having a similar cyclic oscillation. This view holds that (1) a saccade is initiated during a fixation period after some processing requirements have been met, (2) following this command a movement of the eye follows in time-locked fashion, (3) commencing a new eye fixation which supplies new sensory information to the cortex (after some afferent delay), (4) certain processing requirements for eye movements are again satisfied, either dependent upon the interpretation of this information or independently, and (5) another saccade is programmed and the command to move the eyes is issued. In accepting this view one must speak of the "complete eye movement cycle" (Russo, 1978, p. 91) of which the actual saccade is but one stage. Programming the saccade and responding to the visual feedback provided by a new fixation are equally important stages. According to a serial view the complete cycle must be completed in order to begin anew, as the need to seek new visual information occurs after some processing of the currently fixated information.

The now familiar debate about whether the specifics of the saccadic response are determined after evaluating the contents of the current fixation, or, if this decision is based on information acquired

on previous fixations is indicated above in point 4. Neither view questions the implicit belief that the actual command which irrevocably triggers a motor response is generated and instantiated during the immediately preceding fixation, after information has been picked up. Preprogramming models of eye control maintain that the details of the saccade are determined before this pick-up has occurred. For some period the details are not actively processed to bring about a change in eye position, but are stored in a memory buffer (Potter, 1983) until information has been obtained, and then the command is actually issued. Thus, in preprogramming as well as direct control, in a definite sense saccades beget fixations which spawn new saccades, begetting new fixations, and so forth, in a cyclical but strictly serial chain.

In contrast, parallel programming of saccades occurs when more than one eye movement cycle exist concurrently. This is possible because the mechanism which begins an eye movement is not dependent upon receiving visual input delivered by the prior saccade. A saccadic response may be actively processed to bring about a change in eye position even while an earlier saccade has yet to shift the eye to a new position. As Becker and Jurgens (1979) have demonstrated, if the programming of the earlier saccade is enough in advance of the following one so that they do not co-occur at the same stage of processing, two independent eye movements are executed with a very brief intervening fixation pause. If the second response follows quickly on the heels of the first, they may compete for processing at various stages resulting in complex interactions. A partial or

complete redirection of the first saccade is seen.

Parallel programming is distinctly different from preprogramming or from "grouped" programming which would predict uniform, average fixation pauses and no interactions between successive saccades. Like parallel programming, these other models assert that something related to a saccade is done before the fixation immediately preceding it has begun, but they do not concur with parallel programming on just what is done. Parallel programming claims it is everything possible, time allowing; the desired eye position is chosen, programmed into the necessary motor command, and transmitted, causing a saccade (call it saccade N) in a time-locked manner. If the eye happens to move during any portion of this latent period as a result of an earlier saccadic response (N-1), the duration of the fixation period preceding saccade N will not have any systematic length. It will simply depend upon how far programming has progressed before the intervening (N-1) movement. The fixation duration before saccade N will simply be the time required to complete the programming and initiate the movement. (Thus, short fixations should be found following instances of parallel programming.)

Preprogramming, as the term implies, is the state of affairs wherein the spatial and/or temporal metrics of a saccade are determined during a preceding fixation period, but not put into effect at that point. They are stored for later use, during the following fixation, where the information is instantiated as an eye movement command and released. Preprogramming theorists have suggested that in reading the duration of the next fixation may be preset based upon the length of

the upcoming word as seen in parafoveal vision (Vaughan, 1983), or simply set to a rhythmic pulse as part of a motor routine (Levy-Schoen, 1981). In both schemes, the eye movement would not bear a systematic temporal relationship to the occurrence of the preselecting event but to the saccade that precedes it, that is, the fixation duration would be of systematic length.

In order to further discriminate parallel and serial programming of saccades it is necessary to specify in detail the temporal nature of eye movement decisions occurring centrally and their relationship to external events. This viewpoint has recently been propounded by McConkie (1983) and McConkie, Underwood, Zola, and Wolverton (Note 1).

First of all, a significant time lag is associated with the neural transmission of stimulation between peripheral and central structures (McConkie, 1983; Russo, 1978). Activity in the visual cortex lags behind retinal events in real time by approximately 50 - 60 msec. A logical consequence of this following the short saccades made in reading, which last about 30 msec, is that at the beginning of fixations, the brain will still be processing an image created by the previous fixation, while any stimulation due to the onset of the saccade would have yet to reach the cortex. In principle, about 50 msec after the saccade onset, perhaps 20 msec into the new fixation, saccadic smear should reach cortex. Recently though, Breitmeyer (1983) has theorized that interactions of highly specialized neurophysiological subsystems allow us to see no perceptual gap caused by a saccade, but simply one spatiotopic image which extends through

the saccade period and incorporates new information when contents of the new fixation arrive. Thus, for 80 - 90 msec after a fixation ends, the brain will still be processing that fixation. About 50 msec after the new fixation starts, updated information will begin to reach the cortex. Any saccade initiated in these 50 msec before the last image has been written over, though technically not overlapping with the previous saccadic movement, would still overlap with the total eye movement cycle, in violation of a serial alternation scheme. The apparent latency of such a saccade would be greatly reduced, indicating parallel programming.

Also, after excitation first arrives at the visual cortex some finite period may pass before a clear percept develops. Russo estimates the duration of this period at 60 msec from tachistoscopic studies and rapid serial visual presentation (RSVP) experiments. Close agreement was reported in an actual reading experiment by Rayner, Inhoff, Morrison, Slowiaczek, and Bertera (1981). They found that limiting readers to a mere 50 msec presentation of text (followed by a mask) hardly diminished reading performance at all. Added to the afferent latency, this would yield a lag of at least 100 msec between stimulus onset and the completion of strictly visual processing leading to a full-blown percept.

On the other hand, brain events affecting eye behavior, that is, eye movement commands, necessitate information transmission in the opposite direction, also with an inherent time cost. The time required for a motor command to traverse efferent pathways and cause the eye

muscles to contract is estimated by Russo (1978) at 30 - 45 msec, from a wide range of sources.

Finally, between the perceptual and motor processes there must be some intervening internal processes. A consensus on the nature and duration of these processing stages does not exist. Included must be, (1) high level cognitive processes associated with reading - lexical access, language processing, and semantic evaluation; (2) a mechanism to initiate or request a new fixation; and (3) determination of the spatial location of the new fixation. Some authors omit one or more of these stages either explicitly or by denying that they take measurable time. In the context of mental chronometry that cradles information processing theory this amounts to denying their existence as rate-determining elements requiring central processing, and assumes they are carried out in an automatic and tangential fashion.

Stage one is not an essential stage in eye control in general, but is unique to reading. It would not be found in a simple oculomotor latency task. An analogous stage with a different composition would be found in other cognitive-laden eye movement behaviors - picture viewing, visual search, arithmetic calculations, etc. This stage is usually assumed to account for the lion's share of variability in fixation durations (Just & Carpenter, 1980), making eye monitoring a reasonable research tool for studying cognitive processing during reading (Rayner, 1978). Thus the duration of this stage can in principle be very short for some eye movements, while very long for others depending upon psycholinguistic and semantic processing. It is

necessary that all other stages, those concerned strictly with visual feature processing and motoric programming, exhibit much less variability for the approach to have utility. That Russo does not discuss stage one may indicate that he is concerned only with discussing the eye control aspect of reading, not reading itself.

However, Russo's omission of stage two is problematic. Similarly, Just and Carpenter fail to recognize either stage two or stage three. They claim that the time required to initiate an eye movement is but the 30 msec required for efferent transmission of a motor response. In their model, after the current word has been processed as much as possible, some ill-defined, instantaneous mechanism causes a saccade to the next word. They suppose that the direction and amplitude of the saccade is automatically predetermined due to a lack of uncertainty about such in reading. Just and Carpenter's model is almost certainly in error on both points. Saccade lengths are actually quite variable, and unambiguous data exists to show they are not preprogrammed, but directly controlled (Rayner & Pollatsek, 1981). Furthermore, these decisions take real time, no matter how predictable (Arnold & Tinker, 1939; Rayner, Slowiaczek, Clifton, & Bertera, 1983; Salthouse & Ellis, 1980). The present experiment corroborated many studies which point to a central-to-peripheral latency much longer than 30 msec.

That some definable process irrevocably initiates the saccadic response is critical, for by determining the onset of the next eye movement it is the mechanism controlling fixation duration. This must occur either as a natural culmination of the higher level processing in

the preceding stage or by some mechanism monitoring the status of those processes (McConkie, 1979).

Available evidence supports the notion that initiation exists as an isolable process prior to amplitude computation. In reading data, a lack of correlation between adjoining fixation durations and saccade lengths has been interpreted as evidence that eye movement control is dual-process, consisting of separate decisions of when and where to move (Rayner & McConkie, 1976). Also, double-step experiments find that even though irrevocably committed to, a saccadic response to the first target step can be redirected closer to the final target position. An interesting and crucial point is that the latency of this amplitude-modified response is a function of the first step of the target, not the second.

In Becker and Jurgens's model, the saccadic decision stage initiating a response is equivalent to a directional decision, activating either a go-right or go-left oculomotor pathway. They estimate the duration of this stage at around 100 msec. Their experiment was a target-following task with directional uncertainty. It's often argued that such data are not appropriate in reading where direction may be known or highly predicted to be rightward (Just & Carpenter, 1980). However, to assume or preprogram a rightward movement is not tantamount to completely executing this step ahead of time, for once this process is finished, a saccade is irrevocably committed to and amplitude computation commences (Becker & Jurgens, 1979). That would be inconsistent with preprogramming. Thus,

expecting to make a rightward saccade still necessitates some real-time process which produces a "go" signal. Becker and Jurgens estimate the duration of the subsequent amplitude computing stage at around 100 msec. Since they used stimuli requiring 15, 30 or even 60 degree saccades, the above values may overestimate the requirements of either process in reading where eye movements are a full order of magnitude smaller. Russo hypothesized that amplitude determination takes 50 msec, which is in agreement with more recent empirical evidence (Pollatsek & Rayner, 1982).

The Role of Attention in Eye Guidance

What is the nature of the discrete brain process which irrevocably causes a saccade? One possibility is that it is an internal attention shift. The concept of attention and its relation to eye movements had been curiously absent from models of eye control in reading, or occupied only a minor role, until McConkie's groundbreaking article appeared in 1979. Perhaps this was because the study of attention had traditionally been tied to dual task paradigms. In fact, the reading equivalent of shadowing has been cleverly demonstrated (Neisser, 1969). But normal reading is single-channel, so to speak, and attention may have seemed superfluous. Apparently it was thought that visual attention and eye position were utterly redundant. Posner (1980) termed this the common system hypothesis in his comprehensive review. Although many people would reject this thesis, noting that spatial attention can be dissociated from eye position (cf. Kaufman &

Richards, 1969; Engel, 1971), they would probably agree that the two are typically yoked. This is the functional relationship hypothesis (Posner, 1980). Thus, even if not shifting in lock-step, during most of a fixation attention is presumably centered with the fovea. As it was once thought that visual processing at the beginnings and ends of fixations was nullified by saccadic suppression (Haber & Hershenson, 1973), the common system model may have been accepted for all intents and purposes as correct. Fixations were thought of as brief foveal "snapshots". It is now believed that saccadic suppression does not spill over into the fixation pauses in the case of suprathreshold stimuli (Rayner, et al., 1981; McConkie, 1983). With perception extending throughout the fixation period the question of the relative timing between attentional shifts and saccades becomes relevant for reading.

A third theoretical position described by Posner is the efference hypothesis. The idea is that an internal shift of spatial attention automatically causes an eye movement to the attended position. This would seem to apply to target tracking experiments where the sudden appearance of a light in extrafoveal vision elicits orientation. But is it true of all saccades in general? Remington (1980) and Klein (1980) have shown that attention shifts need not precede all saccades. But this finding obtained only in situations where a peripheral signal did not elicit the saccade or the task was unnatural, say, saccading in the opposite direction from the target. Importantly, oculomotor latency was markedly inflated in such cases. For fast-latency,

target-elicited saccades the efference model seemed to hold: Threshold determinations revealed enhanced processing at the spatial locations of the next fixation, before the saccade occurred, indicating an attention shift preceded the saccade to the landing site.

McConkie (1979) has suggested the efference model may operate in reading as well. Although normal reading involves static stimulus arrays devoid of suddenly occurring targets, he suggested that spatial attention discretely shifts across the text and is the mechanism triggering eye movements. Evidence does exist for attention shifts preceding shifts of the visual axis in reading. It is well-known that the perceptual span is asymmetric, biased towards the direction of reading (i.e., left to right for English). Similarly, enhanced processing at the location a saccade will be made to (Rayner, McConkie, & Ehrlich, 1978; Rayner, McConkie, and Zola, 1980) underlies integration across saccades in reading (McConkie & Zola, 1979). As McConkie noted, attentional processes during fixations in reading could elicit eye movements naturally, without the need for a separate mechanism monitoring the reading process and deciding when to order a saccade. The idea is that reading involves attending to the spatial locus of the information being processed (cf. Kennedy, 1983). Thus as reading progresses, attention shifts, which causes saccadic programming to commence. The high level information processing stage and the attention shifting stage overlap. No extra procedure need be executed to decide when to move. However, McConkie's model is still a serial one, which imposes another problem.

The difficulty is that the attention shifting explanation would seem to predict that the eyes would fixate each and every point attended to. This does not necessarily mean every letter, for the case can be made that fluent readers attend to words as unitary wholes. For the most part, a fixation placed in the preferred viewing location (Rayner, 1979b) of a word will allow successful encoding, even on long words because context will combine with featural processing to allow successful word identification (O'Regan, 1981; Rayner, 1979c). Even so, the model would predict that by reading every word we would fixate every word. This is clearly false. Hogaboam (1983) reported that 40% of the words in a text were skipped even during careful reading. These tend to be short, high frequency words, of course. It's reasonable that these could be perceived in parafoveal vision without being fixated. To accommodate this fact McConkie amended his hypothesis by saying that attention to a parafoveal area does not elicit an eye movement unless visual processing is failing to gain adequate information there. But this negates the parsimony of the original hypothesis. Some new process-monitoring step is needed to evaluate the efficacy of visual processing and gate the attention-saccade circuit. This process-monitor increases the complexity of the eye control model just as the others McConkie (1983) objects to, and must interject a time element of its own, as argued above. This could be avoided by simply eliminating the construct and allowing any attentional shift to initiate saccadic programming. But this would prove wasteful. Because the model was couched in a serial framework, it would have the reader

looking at words which did not need to be foveated, having been encoded parafoveally on the previous fixation.

Outline For An Eye Guidance Model Incorporating
Parallel Programming of Saccades

The present experiment was designed to distinguish direct control models from preprogramming models. Since the data offered full support to neither model, I reject the common assumption that the internal processes controlling eye movements are (necessarily) serial in nature. Instead, a direct control model of eye guidance allowing parallel programming of saccades can account for the present results and also predict a host of phenomena regularly seen in eye movement records which are not explained by serial control models. Parallel programming is suggested as a viable mode of eye guidance in reading but by no means a mandatory one. Saccades may be predominately programmed in a serial manner, but do not have to be. If saccades during reading can be programmed in parallel then some saccades will not appear to be programmed in response to the immediately preceding fixation because they were programmed or initiated during the previous fixation. The effects of a mask presented on the immediately preceding fixation will be probabilistic, depending on whether and how much the next saccade began programming before the current fixation was processed. If it has not, control would be serial and the mask would very much affect the occurrence of the next eye movement. In the present experiment, this resulted in a delay in seeing the stimulus and perhaps some general

disruption as well which caused these fixations to lengthen by an amount greater than the duration of the mask. If the saccade has been programmed in parallel to some degree, whether the mask will influence the saccade depends upon how far along programming has proceeded. Sometimes it will be too late to allow any influence. The saccade will be irrevocably initiated and only an efferent lag will delay its actual time of occurrence from the beginning of the fixation, resulting in a very short fixation duration. Other times the programming will have only progressed to early stages and new information will be received in time to modify the amplitude of the saccade, delay, or cancel it.

When parallel programming of saccades is incorporated in an efference model of eye control similar to that outlined by McConkie, the model becomes much more flexible, and can then totally dispense with any process-monitoring of the success of visual processing. The new model has only two assumptions: (1) that shifts of internal spatial attention automatically initiate saccadic programming, and (2) that multiple shifts of attention can occur while processing the same visual image, that is, without waiting for visual feedback from earlier attention-saccade shifts.

Regarding the first assumption, like any neuropsychological process it is reasonable to posit a threshold for eye movement initiation which the attention shift must exceed. Thus, extrafoveal attentional allocation may have to exist for a minimal time in order to make an eye movement irrevocable and begin the amplitude computation stage. Carpenter (1981) presents just such a notion and develops

sophisticated mathematical reasoning which explains how an attention shift must surpass a threshold in order to elicit a saccade. He suggests such "inertia" may be a good thing because it prevents the oculomotor system from being hypersensitive to fluctuations in attention, which would cause the eyes to spend all their time in flight, not sight. Similarly, Becker and Jurgens theorize a threshold in their right-or-left decision stage, which takes 100 msec to complete, but its unclear whether this estimate applies in reading where the amplitude of the attention shifts are generally much smaller. In any case, once the spatial attention threshold is exceeded an eye movement in that direction is irrevocably committed to and control passes to the amplitude computation stage, which also takes time.

Unconstrained by the model is what language processing activity causes attention to shift. Unlike McConkie, I shall not limit it to visual encoding processes. Certainly attending to letter and word processing will cause fixation of those loci, but already encoded words may continue to be attended during higher level syntactic and semantic processing, which would cause fixation of their physical locations in space (cf. Kennedy, 1983). This could be a reason for the small saccades seen in reading - those bringing the eye to a letter already in the fovea on the preceding fixation - which so trouble McConkie. He notes that these are not likely to be seeking new visual information because such would have been perceivable on the prior fixation. Instead, these simply index small changes in the allocation of spatial attention, like microsaccades seen during steady fixation tasks (Cunitz

& Steinman, 1969). It is assumed that the eye is unaware of the impetus for attention shifts; any suprathreshold shift will elicit a saccade.

The model does not constitute a paraphrase of Just and Carpenter's (1980) immediacy hypothesis, which in its strictest interpretation, along with their eye-mind assumption, implies a dead time. As Potter (1983) has argued it is likely that attention is shifted to new text while processing is still occurring at some level on the fixated word. Indeed, under a radical form of the immediacy hypothesis it would be hard to decide that all possible processing of a word had completed, or all possible interpretations of a sentence fragment were exhausted before moving on. In continuous language processing the most powerful way for advancing comprehension of a word may be to obtain information about the next word which would constrain interpretation of the former. Therefore it is assumed that spatial attention shifts over the text in a manner to gain all possible information from the currently perceived image in order to advance ongoing cognitive processes.

Thus, internal shifts of spatial attention are not merely a crutch for bringing about an eye movement which will allow foveal inspection of new text in get-next-input fashion. Rather, spatial attention shifts are integrally linked with active processing. Language processing continues on the now-attended information in the same visual image. (Once the shift exceeds the threshold it elicits a saccade, which happens to be an effective response because it places the high-acuity fovea on the region attended.) If language processing

continues to advance, spatial attention will again shift, eliciting another eye movement. Multiple attention shifts on the same visual image will lead to parallel programming of saccades. Wolverton and Zola reported pilot data which indicated that language processing can advance far to the right of the fixated word. They tried suddenly removing text from a CRT, and found that subjects sometimes can report "several words beyond the fixated word" (1983, p. 49).

Saccades programmed in parallel may interact with each other depending upon timing factors and spatial patterns, as in double-step demonstrations. The possible scenarios will be illustrated by considering just one spatial pattern of attentional shifts in reading - that of attending to two successive words, in left-to-right manner. The same framework could be used to explain regressive eye movements and attention shifts, or intraword shifts of attention and fixation. These are simply cases where attention is directed to areas of the visual field other than the word to the right of fixation. The reversed direction of regressions would lead to slightly different predictions as far as the exact temporal parameters, because they would be instances of "crossed" responses (Becker & Jurgens, 1979).

Saccadic programming, as outlined above, consists of two distinct stages, initiation and computation. Saccadic execution consists both of efferent motor transmission and the saccade itself (combined for the present), and finally, a complete eye movement cycle involves afferent transmission and processing of new visual information. Parallel programming can begin during any of these four periods, and each will

result in a different general class of eye behavior, as will be discussed below.

To begin, suppose language processing advances to the next word to the right of the currently fixated word. Attention shifts, allowing enhanced processing of the information there as the reader attempts to encode the word. Sometime thereafter, the rightward allocation of attention will exceed threshold and irrevocably initiate the programming of a movement to the right, as computation of the necessary saccadic amplitude (defined in spatiotopic coordinates of eye position) begins. Now, the reader may be successful in encoding the word, and if the word needs little or no further interpretation, attention may shift further, to the second word to the right of fixation. If this occurs before or just as the temporal threshold to elicit the first saccade is reached, the eye movement which begins programming will have its spatial extent dictated by the locus of attention prevailing when the threshold is exceeded, that is, the second word to the right. A saccade will be programmed and executed to that point, skipping completely the intervening word. This would most likely occur on short, easily seen, high frequency words. That these are the kind of words which can be perceived parafoveally is well documented (Rayner, et al., 1981).

If the second spatial attention shift does not occur until amplitude computation for the first one is underway, the saccade will be at least partly directed to the location of the first word and partly to the second.[2] The relative balance depends upon how quickly

the second shift follows the first, to redefine desired eye position during the amplitude computation stage (as in Becker and Jurgens' model). If the time spent attending to the two words is roughly balanced, the saccade might land in the region between them, a pattern seen not infrequently in eye movement records. This pattern is hard to explain by the preferred viewing location hypothesis (O'Regan, 1981; Rayner, 1979b) or by McConkie's model, as it is unlikely that this would be where visual encoding processes would fail. Though the saccade is partly determined by the location of the first word, this pattern is usually taken to represent a saccade to the second word, in order to begin a fixation devoted to processing text to the right. This is predicted by the parallel programming model and it is corroborated by recent data. Hogaboam (1983) reported that the frequency of a skipped word predicts the duration of the fixation preceding it, but not following it; that is, the word is processed on the fixation prior to being skipped.

In another scenario the parafoveal encoding of the first word does not succeed before amplitude computation is completed, after which the motor command is issued which will cause a saccade to land on the preferred viewing location of the first word, after an efferent lag and the time required for the saccade itself. During this period, suppose parafoveal encoding now succeeds. Having just encoded the word on the basis of current parafoveal information, attention shifts to the second word to the right and will elicit another saccade. The second saccade will have its amplitude computed somewhere during the very beginning of

the fixation on the first word and will be issued even before the new information gets analyzed at a cortical level. In this case the fixation pause on the first word would be extremely brief, perhaps no more than 50 to 100 msec. Throughout such a brief fixation the model predicts that attention is directed to the next word and a saccade there is imminent. This type of fixation would never be predicted by a serial model: Do such responses legitimately occur? In fact they do. Fixation durations of less than even 100 msec are occasionally seen in reading, landing on words and preceded and followed by saccades of normal amplitude (cf. Just & Carpenter, 1980, p. 330). These are usually on short, high frequency words, as would be predicted. Although they are often paid little attention by eye movement researchers, fixations of less than 100 msec appear in many published frequency distributions (Bouma, 1978; Rayner & Inhoff, 1981).

Finally, suppose the time between the two attention shifts is longer yet. Just after the saccade occurs to the first word, while its parafoveal image from the previous fixation is still being processed centrally, it is encoded and integrated. Attention is shifted to the next word as information from the current fixation reaches the cortex. This information could redirect attention and impact on the initiation and/or amplitude computation process to allow direct control; either by aborting any eye movement before it had exceeded the initiation threshold, or by modifying the amplitude of the saccade in the computation stage. In the present experiment, when a 15 character mask was presented it probably intruded into the word to the right of

fixation where attention was allocated. and disrupted any saccadic programming in that direction. The 5 character mask did not usually extend into the next word, and did not disrupt the programming of a saccade to it. Therefore, on saccades that were in some stage of programming when the mask arrived centrally, a 15 character mask tended to raise some fixation durations if it was present about 150 msec before the eye movement, while a 5 character mask did not. This explains why 15 character masked fixations were more likely to be elongated and wait out the mask while 5 character masks were more likely to produce anticipations, and why saccade lengths were longer for anticipations on the 15 character masks.

Of course, word encoding in parafoveal vision may be the exception not the rule. When it does not succeed, eye movement control will be serial. Attention will be directed to the first word to the right, which will then be in the fovea after the eye movement. Any foveal masking stimulus will disrupt the processing of this word and cause an increase in fixation duration as found here and by Rayner and Pollatsek. Serial programming is the default condition which parallel programming reduces to when parafoveal word encoding does not succeed. Certain conditions may encourage more serial control than others. Decreased parafoveal perceptability due to physical factors of legibility, lack of contextual constraints, or unfamiliarity and difficulty with the text all could force the eyes into a predominantly serial, word-by-word mode. This reading would not be abnormal, but just slightly hindered, by eliminating those occurrences of parallel

programming.

Even though programming may often be serial, the notion of parallel programming is central to a model of eye control in reading. First, it allows all eye movement data including anticipation-type responses to be explained as a result of direct control, eliminating the need to posit additional mechanisms for preprogramming or buffering of information. For instance, it explains nicely why Rayner and Pollatsek (1981) found that saccade length was immediately controlled by the size of a window on fixation N yet was also partly affected by window size on fixation N - 1.

Secondly, it can account for the large variance found in oculomotor parameters which a sufficient theory of eye control in reading must address. For example, if reading consisted of fixating every word and only processing the word fixated, then reading studies could be conducted with tachistoscopes. The reason eye control in reading is a topic worthy of study is that the eyes do not fixate each and every word, one after the other in perfect left-to-right fashion. To fully understand reading we seek to explain the variability and economy of eye movement which contributes to the fluency of reading. Parallel programming offers a parsimonious explanation for word-skipping and for extremely brief fixation durations without positing extra process-monitoring devices to accomplish this.

The model outlined here is a tentative step. So much remains unknown about the internal processing events involved in parallel programming and saccadic initiation. But the model holds promise, for

if the approach should prove fruitful it will not only advance our understanding of eye movement control in reading, but it will also combine in a detailed and meaningful way two of the oldest areas of study in human experimental psychology; attention and eye movements.

FOOTNOTES

1. This has also been referred to as preprogramming, but using the term in a different sense than has been implied in the reading literature, where the flavor is of presetting the duration of fixations or programming more than one saccade at once with an optimal pause in between. (Which would never be set too short in this context.) In reading models it is generally not intended that a saccade may actually be committed to and initiated so that it will commence after an efferent latent stage, while a previous saccade is still in a latent period or in flight.

2. The second attention shift will also commence an amplitude computation stage, serving to program a second eye movement which will position the eye correctly on the second target, and is typically considered a "corrective saccade" in the double-step literature. Of course, in reading, attention could shift yet again and this second saccade might also be redirected farther down the line.

REFERENCE NOTE

- Note 1. McConkie, G.W., Underwood, N.B., Zola, D., and Wolverton, G.S.
Some temporal characteristics of processing during reading.
Manuscript submitted for publication, 1983.

REFERENCES

- Arnold, D.C. & Tinker, M.A. The fixational pause of the eyes. *Journal of Experimental Psychology*, 1939, 25, 271-280.
- Becker, W. & Jurgens, R. An analysis of the saccadic system by means of double-step stimuli. *Vision Research*, 1979, 19, 967-983.
- Bouma, H. Visual search and reading: Eye movements and functional visual field. In J. Requin (Ed.), *Attention and Performance VII*. Hillsdale, N.J.: Erlbaum, 1978.
- Bouma, H. & de Voogd, A.H. On the control of eye saccades in reading. *Vision Research*, 1974, 14, 273-284.
- Breitmeyer, B.G. Sensory masking, persistence, and enhancement in visual perception and reading. In K. Rayner (Ed.), *Eye Movements in Reading: Perceptual and Language Processes*. New York: Academic Press, 1983.
- Buswell, G.T. How adults read. *Supplementary Educational Monographs*, 1937, No. 45.
- Buswell, G.T. Remedial reading at the college and adult levels. *Supplementary Educational Monographs*, 1939, No. 50.
- Carpenter, R.H.S. Oculomotor procrastination. In D.F. Fisher, R.A. Monty, and J.W. Senders (Eds.), *Eye movements: Cognition and visual perception*. Hillsdale, N.J.: Erlbaum, 1981.
- Clark, M.R. A two-dimensional Purkinje eye tracker. *Behavior Research Methods & Instrumentation*, 1975, 7, 215-219.

- Cornsweet, T.N. & Crane, H.D. Accurate two-dimensional eyetracker using first and fourth Purkinje images. *Journal of the Optical Society of America*, 1973, 63, 921-930.
- Cunitz, R.J. & Steinman, R.M. Comparison of saccadic eye movements during fixation and reading. *Vision Research*, 1969, 9, 683-693.
- Dearborn, W.F. The psychology of reading. *Archives of Philosophy, Psychology, and Scientific Methods*, 1906, No. 4.
- Duke-Elder, S. *System of Ophthalmology*, Vol. 6. St. Louis: C. V. Mosby Company, 1973.
- Engel, F.L. Visual conspicuity, directed attention and retinal locus. *Vision Research*, 1971, 11, 563-576.
- Haber, R.N. & Hershenson, M. *The psychology of visual perception*. New York: Holt, Rinehart, & Winston, 1973.
- Hallett, P. & Lightstone, A. Saccadic eye movements to stimuli triggered by prior saccades. *Vision Research*, 1975, 15, 99-106.
- Henson, D.B. Corrective saccades: Effects of altering visual feedback. *Vision Research*, 1978, 18, 63-67.
- Hogaboam, T.W. Reading patterns in eye movement data. In K. Rayner (Ed.), *Eye Movements in Reading: Perceptual and Language Processes*. New York: Academic Press, 1983.
- Huey, E.B. *The Psychology and Pedagogy of Reading*. New York: Macmillan, 1908.
- Just, M.A. & Carpenter, P.A. A theory of reading: From eye fixations to comprehension. *Psychological Review*, 1980, 87, 329-354.

- Kaufman, L. & Richards, W. Spontaneous fixation tendencies for visual forms. *Perception & Psychophysics*, 1969, 5, 85-88.
- Kennedy, A. On looking into space. In K. Rayner (Ed.), *Eye Movements in Reading: Perceptual and Language Processes*. New York: Academic Press, 1983.
- Klein, R. Does oculomotor readiness mediate cognitive control of visual attention? In R.S. Nickerson (Ed.), *Attention and Performance VIII*. Hillsdale, N.J.: Erlbaum, 1980.
- Kolers, P.A. Buswell's discoveries. In R.A. Monty and J.W. Senders (Eds.), *Eye Movements and Psychological Processes*. Hillsdale, N.J.: Erlbaum, 1976.
- Leisman, G. Ocular-motor system control of position anticipation and expectation: Implications for the reading process. In J.W. Senders, D.F. Fisher, and R.A. Monty (Eds.), *Eye Movements and the Higher Psychological Functions*. Hillsdale, N.J.: Erlbaum, 1978.
- Levy-Schoen, A. Flexible and/or rigid control of oculomotor scanning behavior. In D.F. Fisher, R.A. Monty, and J.W. Senders (Eds.), *Eye movements: Cognition and visual perception*. Hillsdale, N.J.: Erlbaum, 1981.
- Levy-Schoen, A. & Blanc-Garin, J. On oculomotor programming and perception. *Brain Research*, 1974, 71, 443-450.
- Levy-Schoen, A. & O'Regan, K. The control of eye movements in reading. In P.A. Kolers, M.E. Wrolstad, and H. Bouma (Eds.),

- Processing of Visible Language. New York: Plenum Press, 1979.
- Mays, L.E. & Sparks, D.L. Dissociation of visual and saccade-related responses in superior colliculus neurons. *Journal of Neurophysiology*, 1980, 43, 207-232.
- McConkie, G.W. On the role and control of eye movements in reading. In P.A. Kollers, M.E. Wrolstad, and H. Bouma (Eds.), *Processing of Visible Language*. New York: Plenum Press, 1979.
- McConkie, G.W. Eye movements and perception during reading. In K. Rayner (Ed.), *Eye Movements in Reading: Perceptual and Language Processes*. New York: Academic Press, 1983.
- McConkie, G.W. & Rayner, K. The span of the effective stimulus during a fixation in reading. *Perception & Psychophysics*, 1975, 17, 578-586.
- McConkie, G.W. & Zola, D. Is visual information integrated across successive fixations in reading? *Perception & Psychophysics*, 1979, 25, 221-224.
- McConkie, G.W., Zola, D., Wolverton, G.S., & Burns, D.D. Eye movement contingent display control in studying reading. *Behavior Research Methods & Instrumentation*, 1978, 10, 154-166.
- McLaughlin, S.C. Parametric adjustment in saccadic eye movements. *Perception & Psychophysics*, 1967, 2, 359-362.
- Neisser, U. Selective reading: A method for the study of visual attention. Paper presented to the 19th International Congress of Psychology, London, 1969.

- O'Regan, K. The "convenient viewing position" hypothesis. In D.F. Fisher, R.A. Monty, and J.W. Senders (Eds.), *Eye movements: Cognition and visual perception*. Hillsdale, N.J.: Erlbaum, 1981.
- Pollatsek, A., Bolozky, S., Well, A.D., & Rayner, K. Asymmetries in the perceptual span for Israeli readers. *Brain and Language*, 1981, 14, 174-180.
- Pollatsek, A. & Rayner, K. Eye movement control in reading: The role of word boundaries. *Journal of Experimental Psychology: Human Perception and Performance*, 1982, 8, 817-833.
- Posner, M. Orienting of attention. *Quarterly Journal of Experimental Psychology*, 1980, 32, 3-25.
- Potter, M.C. Representational buffers: The eye-mind hypothesis in picture perception, reading, and visual search. In K. Rayner (Ed.), *Eye Movements in Reading: Perceptual and Language Processes*. New York: Academic Press, 1983.
- Rayner, K. The perceptual span and peripheral cues in reading. *Cognitive Psychology*, 1975, 7, 65-81.
- Rayner, K. Eye movements in reading and information processing. *Psychological Bulletin*, 1978, 85, 618-660.
- Rayner, K. Eye movements and cognitive psychology: On-line computer approaches to studying visual information processing. *Behavior Research Methods & Instrumentation*, 1979a, 11, 164-171.
- Rayner, K. Eye guidance in reading: Fixation locations within words. *Perception*, 1979b, 8, 21-30.

- Rayner, K. Eye movements in reading: Eye guidance and integration. In P.A. Kolars, M.E. Wrolstad, and H. Bouma (Eds.), *Processing of Visible Language*. New York: Plenum Press, 1979c.
- Rayner, K. & Bertera, J. Reading without a fovea. *Science*, 1979, 206, 468-469.
- Rayner, K. & Inhoff, W. Control of eye movements during reading. In B.L. Zuber (Ed.), *Models of oculomotor behavior and control*. Boca Raton, FL: CRC Press, 1981.
- Rayner, K., Inhoff, A.W., Morrison, R.E., Slowiacsek, M., & Bertera, J. Masking of foveal and parafoveal vision during eye fixations in reading. *Journal of Experimental Psychology: Human perception and performance*, 1981, 7, 167-179.
- Rayner, K. & McConkie, G.W. What guides a reader's eye movements? *Vision Research*, 1976, 16, 829-837.
- Rayner, K., McConkie, G.W., & Ehrlich, S. Eye movements and integrating information across fixations. *Journal of Experimental Psychology: Human Perception and Performance*, 1978, 4, 529-544.
- Rayner, K., McConkie, G.W., & Zola, D. Integrating information across eye movements. *Cognitive Psychology*, 1980, 12, 206-226.
- Rayner, K. & Pollatsek, A. Eye movement control during reading: Evidence for direct control. *Quarterly Journal of Experimental Psychology*, 1981, 33A, 351-373.
- Rayner, K., Slowiaczek, M., Clifton, C., & Bertera, J.H. Latency of sequential eye movements: Implications for reading. *Journal of*

- Experimental Psychology: Human Perception and Performance, 1983, in press.
- Rayner, K., Well, A.D., & Pollatsek, A. Asymmetry of the effective visual field during reading. *Perception & Psychophysics*, 1980, 27, 537-544.
- Reder, S.M. On-line monitoring of eye position signals in contingent and noncontingent paradigms. *Behavior Research Methods & Instrumentation*, 1973, 5, 218-228.
- Remington, R.W. Attention and saccadic eye movements. *Journal of Experimental Psychology: Human Perception and Performance*, 1980, 6, 726-744.
- Russo, J.E. Adaptation of cognitive processes to the eye movement system. In J.W. Senders, D.F. Fisher, and R.A. Monty (Eds.), *Eye Movements and the Higher Psychological Functions*. Hillsdale, N.J.: Erlbaum, 1978.
- Salthouse, T.A. & Ellis, C.L. Determinants of eye-fixation duration. *American Journal of Psychology*, 1980, 93, 207-234.
- Thomas, L. *Pageant of adventure*. New York: Funk, 1940.
- Tinker, M.A. The study of eye movements in reading. *Psychological Bulletin*, 1946, 43, 93-120.
- Tinker, M.A. Recent studies of eye movements in reading. *Psychological Bulletin*, 1958, 55, 215-231.
- Vaughan, J. Control of visual fixation duration in search. In J.W. Senders, D.F. Fisher, and R.A. Monty (Eds.), *Eye Movements and*

- the Higher Psychological Functions. Hillsdale, N.J.: Erlbaum, 1978.
- Vaughan, J. Control of fixation duration in visual search and memory search: Another look. *Journal of Experimental Psychology: Human Perception and Performance*, 1982, 8, 709-723.
- Vaughan, J. Saccadic reaction time in visual search. In K. Rayner (Ed.), *Eye Movements in Reading: Perceptual and Language Processes*. New York: Academic Press, 1983.
- Vaughan, J. & Graefe, T.M. Delay of stimulus presentation after the saccade in visual search. *Perception & Psychophysics*, 1977, 22, 201-205.
- Wheless, L.L., Boynton, R.M., & Cohen, G.H. Eye-movement responses to step and pulse-step stimuli. *Journal of the Optical Society of America*, 1966, 56, 956-960.
- Zola, D. & Wolverton, G.S. The temporal characteristics of visual information extraction during reading. In K. Rayner (Ed.), *Eye Movements in Reading: Perceptual and Language Processes*. New York: Academic Press, 1983.

APPENDIX A

Table 4

Mean fixation duration (in msec) as a function of stimulus onset delay and mask size (in characters) across all SOD manipulations.

Mask Size	Stimulus Onset Delay (msec)				
	0	25	50	200	350
Blocked					
5	238	253	268	305 (360)	304 (513)
15	233	264	278	336 (384)	348 (554)
Random - Equal					
5	245	265	266	299 (357)	314 (531)
15	247	268	292	344 (390)	380 (565)
Random - Long					
5	245	267	289	314 (361)	316 (544)
15	243	291	302	348 (393)	383 (561)
Random - Short					
5	240	258	269	294 (358)	295 (533)
15	238	263	279	344 (390)	368 (587)

Note: Data in parentheses have fixation durations less than the SOD removed. Average of 12 subjects.

Table 5
 Percentage of anticipations as a function of
 stimulus onset delay and mask size (in characters)
 across all SOD manipulations.

Mask	Size	Stimulus Onset	Delay (msec)
		200	350
Blocked			
	5	27.1	73.7
	15	20.8	63.2
Random - Equal			
	5	29.1	69.8
	15	19.4	54.8
Random - Long			
	5	23.4	70.7
	15	19.2	54.4
Random - Short			
	5	31.8	74.7
	15	19.8	61.2

APPENDIX B

The Firing Squad Fell Dead

(Practice story)

Alan MacHardy, Harvard Class of 1940,
was an assistant mine superintendent,
At the famous Pasco Copper Mine, in Peru.
A Peruvian revolution occurred,
and communists captured the copper mine.
Following the communist's policy,
of liquidating all capitalists,
Alan was seized and condemned to be shot.
They took him out, blindfolded him,
and stood him up against a wall.
The firing squad raised their rifles,
and took aim. A volley of shots rang out,
and the firing squad fell dead.
The government troops had arrived,
just barely in the nick of time,
and Alan MacHardy was astonished!

The Pitiful Cry

There was a fire in Brooklyn, in New York,
and out of the inferno came voices,
plaintive childish calls of "Mama, Mama!"
A policeman discovered the blaze,
as he was passing along the street.
He heard pathetic cries of "Mama, Mama!"
Firemen fought the scorching flames,
pushing their way in thru choking smoke.
All the while those baby voices kept on,
pitiously crying out for Mama.
It was pathetic. It was heartbreaking.
The fire was in a doll factory.
On shelves, sat hundreds of talking dolls.
As the fire burned, the shelves gave way -
well, there you have the explanation,
of those innumerable calls of "Mama!"

Accused By Chimpanzees

A vaudeville actor had two trained chimps.

One day he went into the forest with them.

He didn't come back. The chimpanzees did,

and they were chattering excitedly.

The police looked into the matter.

The two chimps led the way into the woods,

where they found the actor - stabbed dead.

On their way back to the neighboring town,

the police stopped at a wayside inn.

Two strangers entered, and as they did,

the chimps went wild. They jumped them,

attacking the two men fiercely.

The police arrested and searched the two -

and found the murdered actor's watch.

The trial was held and the two convicted,

with the chimps as the key witnesses!

Footprints In The Snow

A pilot flying over the Yukon in Canada,
spied some unusual marks in the snow.
They were near a lonely, isolated cabin,
in the wilds north of the Yukon River.
The pilot banked his airplane,
and circled to investigate them.
He saw they spelled out the word H E L P .
He landed in the snow and found a trapper,
dangerously ill with blood poisoning.
The big letters had been made by his wife,
who had trampled them out with her feet.
The pilot put the man into his plane,
and took him to the nearest hospital -
where he was given medical attention,
the help that had been requested -
by the footprints in the snow!

The Sea Cook And The Shark

Elmer Clark was a cook on an ocean liner.
Elmer, the sea cook, liked fishing,
and he thought he'd angle for a shark -
of which there were many in those waters.
He tossed a baited hook out a porthole.
The sea cook didn't have to wait long.
A shark took the bait and started to swim.
It pulled so hard that the cook slipped,
became all tangled up in the line,
and was hauled halfway thru the porthole.
The shark was gradually pulling him thru,
when somebody came and cut the line.
Then they couldn't get the cook out.
He was jammed so tightly in the porthole,
they had to apply grease and ease him out,
before returning him to his pots and pans!

Perils Of A Crash, Drowning, Electrocution, And Train Wreck

A swift little flying story from Austria.
A plane crashed into a high tension wire,
and went plunging on into a lake.
The pilot managed to swim safely ashore.
He then saw that the high tension wire,
which he had knocked to the ground,
lay sprawling across the railroad tracks.
He heard the noise of a distant train.
The express was roaring down the tracks.
The locomotive would run it appeared,
right over the supercharged wire.
The pilot dashed up to the train tracks,
and succeeded in flagging down the train.
There, combined in one swift episode,
were the perils of an airplane crash,
drowning, electrocution, and train wreck!

The Ten Year Old Hero

A three year old girl fell into a well.
The mother, Betsy Quinn, a farmers wife,
ran to the well, feeling utterly helpless.
But she had a boy, a sturdy little fellow.
She told him exactly what to do.
He had spunk and courage, and he did it.
She put him in the bucket and lowered it.
It was done quicker than it can be told.
The boy grabbed on to his drowning sister.
There wasn't room for both in the bucket.
He got out, and hung onto the rock walls,
all the time holding up the little girl.
He put his sister into the bucket,
and the mother hauled her up to safety.
Then the mother sent the bucket back down,
and pulled up her cold, shivering hero!

Fisherman's Luck

A gentleman from Chicago went fly fishing,
in the headwaters of the Ottawa River,
in the wilds of Ontario Province, Canada.
The first cast he attempted missed.
He flipped his line back for a second try;
and got a bite over his shoulder.
This astonished him quite a bit,
as he had seen no water in that direction,
and couldn't imagine trout biting on land.
But he did have a bite all right.
He'd caught a bear at the end of his line.
The hook was firmly embedded in it's ear.
The fisherman took it on the run,
leaving hook, line, flies, and rod behind.
We have yet to hear what the bear did,
with his newly acquired fishing tackle!

Saved From A Parachute

The army was holding parachute maneuvers. All went well until private Harold Osborn, of the Air Corps, stepped out of a plane, intending to drop down through space. But he did not drop. Something was wrong. Perhaps he pulled the rip cord too soon. His lines got tangled in the plane's tail, and Private Osborn hung there, dangling. The plane couldn't land because if it did, the impact would kill Private Osborn. So they flew around for 45 minutes, while other planes came up to the rescue. One threw him a rope; he took a firm hold. Another came up behind him and edged near, so close that a man could cut his lines, and then they hauled him up to safety!

Things Happen At Milford, Utah

At Milford, Utah, things happened fast.

They happened in a blazing succession -
all because an automobile blew a tire.

Howard Hack was driving along the highway,
when his right front tire blew out.

His car swerved wildly off the road,
and knocked down a power line pole.

The wires fell across the railroad tracks,
and that caused a huge short circuit.

Every electric light in Milford went out.

The fireworks from the short circuit,
started a fire at a nearby gas station,
and then the gas station blew up.

The whole town was in turmoil.

Howard Hack, whose blowout started it all,
sustained only a sprained wrist!

The Clue Of The Two Hats

A detective followed a trail for 15 years,
on a single clue and a clever deduction.
A policeman and a bartender were killed,
on the same night, but in different spots.
The clever detective noticed one thing.
In the first murder two hats were found.
One - the victim's. The other - unknown.
In the second crime, no hat was found,
although the victim had been wearing one.
The smart detective reasoned this way -
The murders were committed by one man.
He lost his hat killing the first man,
so he took the second victim's hat.
That reasoning led to other indications,
which pointed the the killer's identity.
It took 15 years, but he was convicted!

A Hero's Error

In the town of Indiana Harbor, Indiana,
Arthur Smith was a courageous fellow.
But he discovered, to his sorrow,
that courage sometimes can cost money.
One day it cost Arthur forty-five dollars.
He saw a robber hold up a man in the road.
Arthur made a dive for the crook,
and knocked the gun out of his hand.
The robber made a quick get-away.
Naturally, Arthur felt pretty good,
and expected some grateful thanks.
But the victim he just saved reached down,
picked up the gun, and put it in his ribs,
and proceeded to hold up Arthur.
He robbed his savior of 45 dollars.
Seemingly a nightmare of ingratitude!

Aviation Rides A Freight

In Texas, Jasper Jones, a mighty aviator,
took off in his plane with two passengers.
He got off the ground but not much higher.
The plane went over the railroad tracks,
where a freight train was rumbling along.
It was then that pilot Jasper Jones,
unable to get his coughing, snorting,
flying bus to stumble any further,
made a highly original landing.
He set her down on top of a cattle car.
The freight train kept on going,
with the plane perched right on top.
Somewhat like a monkey riding an elephant.
Plane a bit damaged, but nobody hurt,
in an episode of aviation taking refuge,
on the top of a freight train!

A Modern-Day Noah

Fred Beene and his wife and three kids,
were sound asleep when the flood came.
The house tipped and the waters poured in.
Mrs. Beene put the children on a high bed.
The house was rocking and pitching,
but they had no idea what had happened -
that their home had become a houseboat.
It was floating down the flooding river.
Then there was a heavy, crashing jolt.
Fred realized this was positively unusual.
He investigated and found that his house -
like Noah's ark - was stuck on a hilltop,
a mile from where they had lived before.
He put his wife and kids out on the hill,
and then climbed to safety himself.
He had been a Noah without knowing it!

Trapped On A Blazing Oil Tank

There was an oil fire in Beaumont, Texas.
On top of a giant tank were three workers,
with flames sweeping around furiously.
At any time that oil tank might blow up -
and the three refinery workers with it.
They rushed over to their ladder,
the only route down to safety. Just then,
an explosion roared, displaced the ladder,
and knocked it out of their reach.
There they were, victims of certain doom -
it seemed. But then - a second explosion,
it also hit the ladder, and sent it back -
right where the workers could get to it.
Down the ladder the three went -
For a dash to safety, just in time.
A minute later the oil tank exploded!

The Man Who Thought He Was A Ghost

Here's a weird episode of a firing squad,
a tale from the Spanish reign of terror.
The chief of police of San Sebastian,
was one of ten victims condemned to death.
With his fellow doomed companions,
he stood before the firing squad.
Just before the volley roared, he fainted.
He fell right before the other victims.
He in a trance, they riddled with bullets.
The executioners noticed nothing of this.
They left the bodies where they lay.
The police chief regained consciousness.
He walked away, thinking he was a ghost.
He was found roaming the countryside,
by fugitives who led him over the border,
to be convinced that he was not a ghost!

The Cry From The Desert

In North Africa, a wireless message,
just one word - "water" - was picked up.
Over and over without variation - "water".
Only too meaningful, on the desert's edge,
only too eloquent, the one wireless word -
"water" - from out of the limitless sand.
It was suspected to come from two pilots,
who had been reported missing for days,
after leaving on a flight over the desert.
A sky search by five planes was organized.
Finally they spotted the missing plane.
It has been forced down on the desert.
The crew had been able, after much effort,
to get their wireless sending set working,
but by then, in such a delirium of thirst,
they could signal only one word - "water"!

Water Instead Of Air

A boy saved his life by drinking water,
while he was buried nine feet underground.
Two curiosity seekers, a father and a son,
were investigating an excavation site,
when suddenly there was a cave-in.
A landslide buried the boy to his waist.
The father saw that more earth would fall.
He tossed him one end of a garden hose.
Just then down came a second landslide.
It buried him beneath nine feet of earth.
He had the hose to provide him with air,
but he found that it was full of water.
He had to drink all of the water first.
Rescuers hooked an air tank onto the hose.
It took two hours before they dug him out.
He was ok - a bit shaken, but not thirsty!

Well, Tickle My Ribs

Ben Fontaine, of Green Bay, Wisconsin,
wasn't a brave man. He was just ticklish.
Nudge his ribs, and he'd hit the ceiling.
In fact, he not only hit the ceiling,
he hit the robber. Ben was held up.
The crook had a gun. Ben punched him -
instead of being a meek victim -
and knocked the criminal out cold.
The Green Bay Police called it heroic.
Ben disagreed, and explained it this way:
"I'm neither brave or foolhardy," he said.
"I was all set to give the crook my money,
But as I was sticking up my hands,
He pushed the gun in my ribs - it tickled.
I can't stand tickling; it makes me mad.
So I took a swing, and down he went!"

Billy's Fatal Banquet

Goats are renowned for their appetities,
and their cast iron-like stomachs.
They can eat almost anything, it's said.
But there's one dinner, in two courses,
that even the toughest goat can't digest.
That was proven at East Peoria, Illinois,
when a billygoat saw a pan of gasoline,
which was being used to clean farm tools.
Billy lapped up the gas as a first course.
Then a workman, having lighted his pipe,
threw the match on the ground.
It was still burning. As a second course,
the goat tried to eat the flame, and -
that was the end of Billy. He blew up.
No, not even a goat can drink gasoline,
if he follows it with a chaser of fire!

Held Prisoner By Whales

We hear alot about prisons and prisoners,
tight corners and curious predicaments.
But this one I bet you never heard before,
held prisoner by over one hundred whales -
that was the story told by five fishermen.
Suddenly the sea churned about their boat,
a huge school of whales surrounded them -
some one hundred and twenty feet long.
The men shut off their motor and drifted -
afraid of disturbing the huge creatures.
For five hours they were prisoners at sea,
trapped by the imprisoning ring of whales.
They were badly scared when, about sunset,
the whole school of whales dived suddenly.
The fishermen went chugging back to port -
to tell that whale of a story!

APPENDIX C

Comprehension Quiz Questions

1. The practice story is an example of:
 1. Yankee imperialism.
 2. haste makes waste.
 3. an amazing coincidence.
 4. good triumphing over evil.

2. In "The Pitiful Cry", the dolls called out "Mama!" because:
 1. they had fallen down.
 2. the fire was hot.
 3. they were frightened.
 4. they were hungry.

3. "Accused by Chimpanzees", provided evidence that:
 1. chimpanzees do not protect their owners.
 2. chimpanzees have good memories.
 3. chimpanzees are vicious animals.
 4. chimpanzees make good lawyers.

4. In "Footprints in the Snow", the sick trapper was brought to the hospital by:
 1. a cross-country skier.
 2. a dogsled champion.
 3. a flier.
 4. his wife.

5. In "The Sea Cook and the Shark", the cook made a mistake by:
 1. using such a big piece of bait.
 2. putting his line thru a porthole.
 3. not keeping a knife nearby.
 4. getting caught in the line.

6. In "Perils of a Crash, Drowning, Electrocution, and Train Wreck", the pilot averted a train wreck by:
 1. pulling the electric wire off the tracks.
 2. signalling the conductor by dipping his wings.
 3. stopping the train before it ran over the electric wire.
 4. throwing a switch to send the train down another track.

7. In "The Ten Year Old Hero", the little boy was heroic because:

1. he kept his head.
2. he wasn't afraid.
3. he could swim.
4. he was small but sturdy.

8. In "Fisherman's Luck", the angler:

1. gave his fishing tackle to the bear.
2. was too scared to think about his tackle.
3. ran away and left his tackle behind.
4. was so fed up he left the tackle on purpose.

9. In "Saved From a Parachute", the skydiver:
 1. jumped too late.
 2. jumped too soon.
 3. was scared to jump.
 4. pulled his rip cord early.

10. "Things Happen at Milford, Utah", about a hilarious chain-reaction, is an instance of:
 1. an improbable sequence of events.
 2. evil sorcery at work.
 3. a million-to-one shot.
 4. plain bad luck.

11. In "The Clue of the Two Hats", the murderer's mistake was:

1. wearing a hat in the first place.
2. trading hats with one of the victims.
3. killing two men who both wore hats.
4. leaving the hat at the murder scene.

12. In "A Hero's Error", about a man who was held up by a hold-up victim he had saved, the moral is:

1. don't get involved in other people's affairs.
2. courageous acts can be expensive.
3. you can never trust anybody.
4. watch out for teams of con artists.

13. In "Aviation Rides a Freight", the pilot was lucky that:

1. he got off the ground at all.
2. he sustained only minor injuries.
3. the cattle cars weren't loaded with cattle.
4. the plane wasn't damaged.

14. In "A Modern-Day Noah", the Beene family had no idea that:

1. there was a flood.
2. they were stuck on a hilltop.
3. their houseboat had traveled a mile.
4. they were floating downriver.

15. In "Trapped on a Blazing Oil Tank", the refinery workers were saved by:

1. quick thinking.
2. pure luck.
3. proper planning.
4. fast footwork.

16. In the story about the police chief who missed being shot by the firing squad, he thought:

1. he was immortal.
2. he was invisible.
3. he was a ghost.
4. he was invincible.

17. In "The Cry From the Desert", the pilots could only signal one word because:

1. their wireless set was barely working.
2. they were too weak.
3. they knew very little Morse Code.
4. they were mad with thirst.

18. In "Water Instead of Air", the young boy was buried alive by:

1. an avalanche.
2. a cave-in.
3. a rockslide.
4. quicksand.

19. In "Well, Tickle My Ribs", Ben Fontaine, the principal character was:

1. neither brave nor foolish.
2. both ticklish and meek.
3. both foolhardy and mad.
4. neither heroic or ticklish.

20. In "Billy's Fatal Banquet", the goat consumed:

1. lighter fluid and a lighted match.
2. gasoline and a lighted cigarette butt.
3. gasoline and a lighted match.
4. 47 times his weight in excess explosives.

21. In "Held Prisoner by Whales", the fishermen tried to:

1. evade the whales.
2. not disturb the whales.
3. catch some of the whales.
4. scare off the whales.

