READING WITH THE ROD VISUAL SYSTEM

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ABSTRACT

People usually read under daylight illumination using their "day vision." Little is known about whether people are able to read exclusively with their night (i.e., rod) vision; and if they can whether reading with the night vision system differs from ordinary reading.

The present research investigates reading with rod vision. A special method of displaying text was devised such that the text could be read with rod but not cone vision. The key features of the method included the use of a blue chromatic filter and the selection of an appropriate luminance range. Results show that this method provides a 3 log unit luminance range over which the observer can read exclusively with the rods.

The first study investigated whether people can read exclusively with their rod visual system. The results show that this is not only possible but that normal subjects are also capable of reading at luminance levels only three times absolute threshold. It is possible that with the present text size that subjects can read at even lower luminance levels near threshold though reading rates would be very low (e.g., approximately 4 to 5 wpm). The reading performance of a rod monochromat was tested over a 4.5 log unit range to investigate the effects of luminance on rod reading performance. Because the monochromat has only rod photoreceptors reading can be tested at high luminance levels where normally cones would mediate reading. The rod monochromat was capable of reading with the rods over the entire luminance range though reading performance was found to plateau at relatively low luminance levels.

The purpose of the second study was to investigate whether people read best by fixating a passage of text (as one ordinarily does) or by viewing the passage with their peripheral vision (where rod night vision sensitivity is maximal). Reading performance was tested with text placed at the point of fixation as well as retinal eccentricities of 5, 10, 15 and 20 degrees below the point of fixation. The results show that, for three degree letter size,

subjects read best when text was placed 5 degrees below or at the point of fixation. This finding was somewhat unexpected because at low luminances subjects are more sensitive in the peripheral retina than near the fovea and because subjects have a foveal scotoma.

In the third study, it was investigated whether reading with rods is faster or slower than reading with cone vision. Text was presented at five degrees below the subject's fixation. The text luminance was equated for rod and cone vision by scaling it relative to the rod and cone absolute threshold. Cone vision was isolated by testing reading during the cone plateau phase of the dark adaptation curve. The results show that subjects read faster when reading the text with cone vision than with rod vision.

In conclusion, reading is not an exclusive property of the cone visual system. Subjects can read even with an image available through the night vision system. Comparisons of rod and cone reading suggest that cone vision allows an observer to read faster than the rod visual system.

Whether reading with the rods or cones, performance of both day and night vision is dependent on the specific luminance level. Subjects' reading performance were found to improve rapidly with luminance at low luminance levels and to plateau once cone thresholds were exceeded.

The results also show that reading is greatly dependent on where in the visual field the text is presented. Subjects can read using the peripheral retina, however, reading performance is much poorer in the peripheral visual field than in the central visual field. This is true even though the subjects had a central scotoma.

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PREFACE

Reading is a complex visual task whose performance depends on many factors including cognition, oculomotor function, as well as vision. In the present investigation, however, we have attempted to minimize the role of the first two factors in order to focus on issues related mostly to vision.

Ordinarily people read with their day vision system. However, because our visual system is duplex, visual images of text can be generated by either the day or night vision systems; thus, raising the question whether people might actually be able to read with their night vision system.

The present investigation deals with whether people can read exclusively with rod vision. That a person can read in dim illuminance does not necessarily prove that reading with the rods is possible. In relatively dim illumination, both the rod and cone visual systems may contribute to the visual image. Therefore, it is possible that the person is actually reading with the cone visual system. To prove that people can read with the rods, the present investigation deals specifically with viewing conditions in which only the rod visual system can see the text. Likewise to investigate reading with cone vision, viewing conditions can be created so that only the cone visual system can see the text.

The general plan of the research was to first develop a method of presenting text that could only be read by the rod visual system (see Chapter I). Then an established psychophysical paradigm was used to investigate whether people could read the text and whether rod reading behavior was amenable to systematic study. This work is described in the first experiment (Chapter I). If it had been found that reading was not possible the experimental plan would have been to explore factors that prevented reading. Because reading was possible, however, a series of experiments were conducted to determine how reading with night vision differs or is similar to ordinary reading (with day vision, see Chapters II & III).

A preliminary report of some of the experiments reported here has been published as a short paper (Chaparro & Young, 1988), a paper (Chaparro & Young, 1989a), and as abstracts (Chaparro & Young, 1989b; Chaparro & Young, 1990).

CHAPTER I

READING WITH THE ROD VISUAL SYSTEM

Introduction

Reading is a human visual function usually performed in daylight using the cone visual system. Reading in the dark with the rod visual system, however, is not a trivial topic for investigation. Knowledge about the human ability to acquire information in dim illumination has significance in both industrial and military applications (Johnson, 1987). In addition, this knowledge may also contribute to an understanding of the nature of certain reading problems incurred by low vision patients.

There are two main reasons why one might question whether reading at luminances near the absolute threshold of vision is possible or is amenable to systematic study. First, experience with certain ophthalmology patients suggests that low vision performance might be characterized by large individual differences and, in some cases, unreliable performance. Second, it is apparent from the psychophysical literature, that substantial difficulties are associated with night vision tasks. Under scotopic conditions, (i) fewer number of photons are available to form a retinal image; (ii) The fovea is a rod-free area and consequently the observer develops a physiological scotoma, i.e., the "Arago phenomenon" (Geldard, 1953). The loss of foveal function is likely to produce deficits in the ability to accurately fixate, track and saccade (Timberlake, Peli, Essock, & Augliere, 1987; Steinman & Cuntiz, 1968); (iii) When viewing the environment only with the rods, the observer has poorer visual acuity (Blackwell & Blackwell, 1961), poorer contrast sensitivity (Daitch & Green, 1969), poorer temporal resolution (Hecht & Shlaer, 1936), poorer accuracy in accommodation (Owens, 1984), and no color vision (Geldard, 1953).

At the present time, little if anything is known about reading performance at luminances near absolute threshold. The feasibility of such an investigation is suggested by a previous study (Legge & Rubin, 1986) which reported on the reading performance of two subjects at a very low luminance (i.e., 0.0006 cd/m^2 , see their Figure 3). The authors concluded that the subjects were in fact reading with "scotopic vision" because, (i) the subjects were unable to identify the hue of the text, (ii) the subjects were unable to read centrally fixated letters, and (iii) the reading performance varied differentially with text wavelengths of photopically balanced luminances.

The goals of the present study were, (i) to investigate the reading performance of normal observers at luminances near rod absolute threshold; (ii) to provide unequivocal evidence that, at the luminance levels tested, only rod photoreceptors mediate the reading performance and (iii) to provide some estimate of how reading performance with rod vision varies with luminance levels.

Method

Subjects

Five graduate students from the Department of Psychology volunteered for the study. All five reportedly were correctable to 20/20 visual acuity and were in good health. All were found to have normal night vision thresholds (as shown in the results); one male subject, however, was a deuteranomalous trichromat. The four men were of ages 26, 27, 27, and 41; the female subject was 24 years old. An 18-year-old, female, rod monochromat recruited from the clinic at the Department of Ophthalmology at Texas Tech University Health Sciences Center also participated in the study.

Apparatus

The video text display (Figure 1) was created from a Radio Shack TRS-80 computer (Figure 2). Software was written to scan upper case characters from right to left across an eight-character window in the center of the computer monitor. In the absence of prior knowledge about the performance near absolute threshold, the window size was chosen to be larger than the minimum window width shown to produce asymptotic performance for photopic reading (Legge et al., 1985a, Legge et al., 1985b). Several sheets of blue filter material (Edmund Scientific #866) were placed over the window in front of the computer monitor. The luminance of the text was controlled by interposing neutral density filters between the subject's eye and the monitor. The text luminance was calibrated from knowledge of the unattenuated text luminance (as measured using a Spectra-Prichard Spot photometer), the effective density of individual "blue" filter sheets, and the density of the neutral density filters.

To provide some magnification of the text and also to aid accommodation in the dark, a +8.0 diopter spherical lens was held in front of the eye by the subject. The subject viewed the computer monitor monocularly from a typical distance of 101 mm. Each character in the display was approximately 3.2 degrees tall; the exact size varied slightly with the actual fixation distance and placement of lens for individual subjects. Four orientation dots demarcated the boundaries of the window. The reading material, on each trial, consisted of 10 four-letter words, randomly selected by the computer from a pool of several hundred words taken from Newsweek and Time magazines. The rationale for using four-letter words in context-free sequence is empirical. It was concluded from preliminary attempts found that the reading performance of ordinary sentences was variable. It appeared that subjects would often miss words of six and more characters. In addition, the probability of correctly reading a word was not independent of the correct recognition of previous words. For example, in ordinary sentences, the probability of reading the object of the sentence is somewhat dependent on

correctly reading the subject and verb. By trial and error, it was ascertained that the four-letter words produced less errors in reading but had sufficient number of letters to give the visual appearance of a word.

Procedure

After initial instruction and a 20- to 30-minute practice session, the subjects were dark-adapted for at least 30 minutes. At the start of each trial, a "GET READY" message was scanned across the screen to help prepare the subject for the oncoming text. The subject was instructed to read the text aloud into a tape recorder as the text was scanned across the screen. The subject was permitted to view the text in whatever manner he/she wished as long as fixation was somewhere within the confines of the window as indicated by the four orientation dots. Generally, the subjects developed the strategy of either gazing toward the right side of the window where the words would emerge or to the left side of the window where the words would disappear. They would only follow the text if the word was not immediately recognized. A session would consist of one replication of a range of different scan rates of text presentations at three text luminance levels and session last between 2 to 3 hours. Altogether each session was replicated five times for each of the subjects over a period of 2 months.

Method of quantifying reading performance. The method used to quantify reading performance was based on that described by Legge and his colleagues in their papers concerned with the psychophysics of reading (Legge & Rubin, 1986; Legge, Pelli, Rubin, & Schleske, 1985; Legge, Rubin, Pelli, & Schleske, 1985). The method used in this study included the determination of reading errors from a comparison of the tape recordings with a printout of the computer-generated sentences. The percent reading accuracy was then multiplied by the scan rate (in words per minute) to obtain "reading rate."

Results

Psychophysical Estimates of the Rod and Cone Thresholds

The claim that the text display was only read by the rods in this situation rests on psychophysical measurements made on the apparatus. Estimates of the rod thresholds were obtained by scanning the text at a rate of about 25 words per minute. The subject was fully dark-adapted and his/her task was to report whether he/she could detect spatio-temporal fluctuations anywhere within the window. This was called the "full window criterion." Figure 3 shows the frequency-of-seeing curves for the five subjects. The text luminance corresponding to a detection rate of 50% was taken as threshold.

Several estimates of cone thresholds were obtained. One estimate was based on the detection of a flickering character (i.e., a minus sign) between two fixation landmarks. The subject was instructed to fixate between the markers and indicate whether he detected the flickering minus sign. This criterion was presumed to reflect the cone threshold with the assumption that the fovea is rod-free and that the cone threshold in the fovea is lower than in the parafovea. The frequency-of-seeing curves corresponding to this response criterion ("foveal window") are shown in Figure 3 on the right side. A second estimate of cone threshold was based on the "full window" criterion. Unlike the rod threshold determination, the subjects were first exposed to a bleaching light for 3 minutes and then tested during the cone plateau phase (which, as had been determined in a separate experiment was between 5 and 10 minutes) of the dark adaptation curve. An estimate was also obtained using a patient who had been diagnosed to have the x-linked recessive form of congenital stationary night blindness with myopia (Young, Price, & Harrison, 1986).

In conclusion, the highest text luminance for which reading is mediated exclusively by the rods is limited by the cone threshold. These results suggest that, on this stimulus apparatus, we can investigate reading with the rods over a 1,000-fold range of text luminance.

Reading Performance at Low Illumination Levels

The reading performance for the first subject (S1) recruited was studied at 1.0, 1.5, 2.0 log units above her absolute threshold. The reading performance of the other four subjects (S2-S5) was studied at lower luminances (i.e., at about 0.5, 1.0, and 1.5 log units above their absolute threshold).

Figure 4 shows the plot of reading rate versus scan rate on a logarithmic scale for each of the three text luminance levels tested. As the scan rate increased, reading rate increased to a maximum and then decreased as the subject made an increasing number of errors. This "inverted U" function appeared to characterize the performance for different text luminances in all of the subjects tested. The effect of increasing the text luminance generally appeared to raise the reading rate across all scan rates.

Maximum reading rate is graphically represented by the peak of the inverted U functions shown in Figure 4. In an attempt to evaluate the reliability of the maximum reading rate, estimates were derived from the first and fifth replications for each text luminance conditions and each subject. Figure 5 shows the maximum reading rate of the first replication plotted against the maximum reading rate of the fifth replication. Pearson's correlation coefficient (i.e., r) between replications for the high luminance condition was 0.93; for the middle luminance, 0.85; and for the low luminance, 0.88.

In Figure 6, the maximum reading rate (derived from the data shown in Figure 4) was plotted as a function of the text luminance. The reading rates of the normal subjects were rather similar (large symbols). For the five subjects tested, it was found that, at low luminance levels, the average reading rate increased by about 40 words per minute for a 10-fold increase in luminance. In additional experiments (Chaparro & Young, 1989b), the reading rates of the normal observers were studied at luminances extending above cone threshold (Figure 6, small open squares). These results suggest that the reading rates may plateau once cone thresholds are exceeded. The reading rate of a rod monochromat (a person

born having an all rod retina) was also studied. Her results also suggest that reading rates plateau at high scotopic luminances.

Discussion

The results of a previous study (Legge & Rubin, 1986) documented that humans can read under dim illumination (see Introduction). But, in the absence of an estimate of their subjects' cone threshold and of the equivalent scotopic values for their luminance levels, it is difficult to reject the possibility that their reading was partly mediated by cone vision. The results of the present study, however, remove this uncertainty as the luminances used in the present study were shown to lie well below the cone thresholds of each subject (see Figure 6). These results therefore provide evidence that humans can read exclusively with their rod visual system.

The results of Legge and Rubin (1986) and of the present study can be compared if allowances are made for differences in the stimulus wavelength and text character size (Figure 6, small circles). The difference in stimulus wavelength was compensated for by expressing the luminance used in the previous study in terms of scotopic Ft-L. Difference in character size (the visual subtense of the letters were 6° in the previous study and 3° in the present study) poses the problem that the absolute threshold for the larger characters is expected to be lower than that for the small characters. To minimize the difference in threshold between the two studies, the data of the previous study was shifted to the right by an amount that would bring their lowest scotopic luminance condition in the range of the absolute thresholds for the present study. When plotted in this way, the results of the two studies are found to be rather similar over the range of scotopic luminances where the two overlap.

Until now, there was little if any information about the minimum luminance required for scotopic reading. These results unequivocally show that four subjects were able to read at luminances as low as three times their rod absolute threshold. We do not know whether the

subjects could have read at even lower luminances as such conditions were not tested. But if we could extrapolate from the data obtained so far, it would seem that some level of reading (albeit, a very slow rate) would be possible near the absolute threshold for detection.

The previous study (Legge & Rubin, 1986) showed that reading rates improved with increasing luminance; but until now, there was no quantitative estimate of how much improvement occurs. On the basis of these results, we estimate that the improvement rate is about 40 words per minute for every 10-fold increase in luminance. This estimate, however, applies to the luminance range over which vision is only mediated by rods. The improvement rate seems to decrease at higher luminances. Whether the decrease in improvement rate is due to rod-cone interaction or to rod saturation warrant further investigation.

There are many interesting questions that are raised by the finding that humans can read with scotopic vision. Perhaps the most intriguing is the question of whether one can use the scotopic vision of normal subjects to understand the reading problems suffered by patients with central scotomas. Thus far, this study demonstrated a relatively inexpensive and simple method for producing an "artificial foveal scotoma." In addition, the results (and those of the previous study) demonstrated that the reading rates for the rod visual system (about 50 words per minute) are comparable to that for patients with foveal loss (Legge, Rubin, Pelli, & Schleske, 1985).

Figure 1. Video display as seen by subject. The inset illustrates that, under the viewing conditions of this study, the subject's fixation is obscured by a central scotoma (as shown here by the obscuration of the letter "A" in the word "BEAR"). Also shown are four orientation dots which mark the boundaries of the window. The inset is somewhat misleading. In the actual experimental apparatus the window was only eight characters wide.

Figure 2. Apparatus used in creating a video text display that only the rods could read. Text is scrolled across a window in a mask (M) that covered the computer monitor (CM) screen. Neutral density (ND) and chromatic (CF) filters were interposed to create suitable scotopic luminance conditions. To provide magnification and help accommodation, the subject viewed the text through a +8 diopter lens (L). Also shown are a tape recorder (TR), printer (P), and computer (CPU).

Figure 3. Psychophysical estimates of rod and cone thresholds obtained on the apparatus. The frequency of seeing curves on the left are for rods thresholds obtained using the "full window" criterion. Shown on the right are estimates of the cone thresholds from several methods. The frequency-of-seeing curves were obtained using the "foveal window" criterion. The arrows on the right are estimates obtained using the "full window" criterion during the cone plateau phase of the dark adaptation curve. The arrow designated CSNB shows the threshold obtained from a night blind patient.

Figure 4. Reading rate as a function of scanning rate for different character luminances. Reading rate is the product of scanning rate and percent reading accuracy. The diagonal line represents perfect reading accuracy at all scan rates. Subjects 2, 3, 4, and 5 were tested 0.5, 1.0, and 1.5 log units above their rod threshold. For Subject 1, the luminances were 1.0, 1.5, and 2.0 log units. The maximum reading rate for a given condition is illustrated by the peak of the function.

Figure 5. Comparison of the maximum reading rate of the 1st replication versus the 5th. The data were derived from those shown in Figure 4 for different subjects and character luminances. The solid line represents the locus of points in which the two replications have identical performance.

Figure 6. Maximum reading rates as a function of text luminance (large symbols). The arrows on the left are estimates of rod thresholds made using the "full window" criterion. The arrows on the right are estimates of cone thresholds made using the same criterion during the cone plateau phase. Results from two additional studies are also plotted for comparison. The small circles are from the previous study of Legge and Rubin (1986) for their subjects DR and MK. The small square symbols are from a study (Chaparro & Young, 1989) investigating the effects of luminance on reading rates of normal subjects (open squares) and a rod monochromat (solid squares).

CHAPTER II
EFFECT OF RETINAL LOCATION OF THE TEXT
ON ROD READING PERFORMANCE

Introduction

As people read they make a series of saccades (i.e., eye movements) which brings parts of the text onto the fovea. Why it is important to place the text on the fovea in reading is not fully understood, but one could speculate that the role of the fovea in reading is related to its high spatial resolution.

Under daylight illumination conditions, the center of the fovea has high spatial resolution. But, under very low luminance conditions, the fovea is blind and the immediately surrounding region no longer has superior spatial resolution. The available evidence documents that, under scotopic conditions, the spatial acuity, temporal resolution, and contrast sensitivity change very little with eccentricity (Hess, Nordby, & Pointer, 1987). Only scotopic detection thresholds which are best at approximately 20 degrees have a specific retinal location where they are optimal (Sloan, 1950). This is in contrast to photopic visual functions such as acuity which drops rapidly with eccentricity (Anstis, 1974).

This raises the question as to where in the visual field scotopic reading will be best. Because the characteristics of the retina do not vary significantly as a function of eccentricity under low luminance conditions (Hess et al., 1987), reading may not be expected to vary with eccentricity. It is also possible that reading may be optimal at 20 degrees where detection thresholds are lowest. It is not known at this point where reading will be best.

Method

Subjects

Five subjects, four males and one female, participated in the study. All of the subjects had normal scotopic thresholds.

Apparatus

The apparatus consisted of a TRS-80 Model 1 computer and monitor. The video monitor was masked except for a small eight-character wide window in which text appeared. A more detailed description of the apparatus is available in Chapter I.

A control board interfaced with the computer was used to control a set of dim red diodes which served as the fixation stimuli. Red diodes were used to provide a fixation stimulus visible to the cones but which would not light adapt the rods. Text was located inferiorly to diodes which were placed at different vertical distances from the center of the text corresponding to eccentricities of -5, +5, +10, +15, and +20 degrees for a viewing distance of approximately 11 cm (see Figure 7).

Eccentricity is defined as the angular distance from the fixation point to the center of the text. For each letter of a word to be at a given eccentricity from the fovea would require that they be placed in a circular pattern around the point of fixation. In this experiment the words were presented horizontally which resulted in the initial and final letters of the word extending further into the peripheral retina than the center. One four-letter word spanned 10.87 degrees. When fixated foveally by the subject the word extended 5.43 degrees to the left and right of the fixation. The same was true at other retinal locations at which reading was tested. For example, at 5 degrees the word extended from 5 degrees to 10.43 degrees, at 10 degrees the word extended from 10 to 15.43 degrees, at 15 degrees the word extended from 15 to 20.43 degrees, and at 20 degrees the word extended from 20 to 25.43 degrees. A computer program was used to serially present ten four-letter words randomly selected from a pool of

three hundred four-letter words. The three hundred words were selected from a list of words most frequently used by college students (Black, Stratton, Nichols, & Chavez, 1985).

Procedure

After initial instruction and a 20- to 30-minute practice session, the subjects were dark adapted for at least 20 minutes. Reading was tested at .75 log units below the mean of the subjects' cone threshold.

At the start of each trial a "GET READY..." message was scrolled across the screen to help prepare the subject for the oncoming text. Each subject was instructed to center him/herself with respect to the window where the text was to appear, to fixate vertically on the diode which was illuminated, and to read the text aloud. Subjects were recorded for later scoring as the text was serially presented on the screen. In the 0 degree eccentricity condition the -5 and +5 degree diodes were turned on and the subject was asked to fixate between the fixation stimuli. In the other eccentricity conditions subjects were reminded of the importance that they maintain eccentric fixation and to report if at any time they looked directly at the text. In such cases the data was discarded and the trial was repeated.

Reading could have been tested in either the superior, inferior, temporal or nasal retina. Reading was tested in the superior retina for a number of reasons. First, by placing the text in the superior retina, variations in the distance of different characters from the fovea were minimized. For example, if the text were presented in the temporal retina the first character of the text would be significantly closer to the fovea than the last character. Second, testing reading in the nasal retinal is complicated by the presence of a blind spot caused by the optic nerve head. Thirdly, the experimental apparatus restricted the view of the screen below the text window making testing of the inferior retina impossible.

Method of quantifying reading performance. Reading performance was quantified by using a method referred to as the standard method (the same as that described in Chapter 1).

The number of reading errors was determined by comparing tape recordings of subject responses to a printout of the actual computer-generated sentences. Reading rates were calculated by multiplying the scan rate (in words per minute) by reading accuracy. The standard method was modified so that rather than scanning the text through the window the individual words were presented serially. Serial text presentation was used to avoid inducing optokinetic nystagmus commonly found when scanning stimuli are used.

The stability of subject fixation was evaluated by recording eye movements while serially presenting text at either 5 and 20 degrees. These two conditions were chosen because they were representative of the reading conditions. Fixation was monitored while subjects viewed text presented on a Apple Macintosh II computer under conditions approximating those of the testing conditions. The subjects' fixation was monitored using a corneal reflection system.

Results

Reading performance was tested with text centered at 0, 5, 10, 15, and 20 degrees. Figure 8 shows the plot of text presentation rate (wpm) versus reading rate for each of five eccentricities. It should be noted that in all subjects, as the text presentation rate increased reading rate increased until a certain point and then decreased. The resulting decrease was due to the subject making greater and greater numbers of errors in identification of individual words.

Figure 9 shows a plot of the estimated maximum reading rates. The maximum reading rate was estimated by first fitting a second-order polynomial function of the form $Y=A+BX+CX^2$ to the data. Then, the maximum reading rate was computed by determining the solution to the first derivative of the best fit function. The reading rate was highest when the subject looked directly at the text and decreased with eccentricity. All subjects showed the same effect of eccentricity on reading rate. One subject, however, did read more slowly when

looking directly at the text than at five degrees. Results of a repeated measures analysis of variance (Kepple, 1982) indicated that there was a significant main effect of eccentricity for the dependent variable reading rate ($F(4, 16) = 53.65, p < .05$).

<u>Source</u>	<u>SS</u>	<u>df</u>	<u>F</u>	<u>p</u>
Eccentricity (A)	76259.34	4	53.65	.0001
Subjects (B)	916.49	4	.	.
A * B	5686.19	16	.	.
Total	83862.02	24		

Tracings of the subjects' eye position while reading text placed at 5^0 and 20^0 eccentricity are shown in Figure 10. The tracings show that the subjects do not need to make downward or upward saccades to read the text.

Discussion

Prior to this study we did not know whether rod reading performance would vary with the location of the text in visual field. There were at least three alternative possibilities; (i) reading may be best in the midperiphery where scotopic sensitivity is greatest; (ii) reading performance may be best when subjects look directly at the text as in reading with the cones. This hypothesis would be consistent with evidence that suggests that the fovea may have unique capabilities. (iii) Finally, reading may not be expected to vary with eccentricity. This hypothesis is based on the observation made by Hess, Nordby and Pointer (1987) showing that scotopic contrast sensitivity, temporal resolution and spatial acuity are nearly constant from the fovea to about 20 degrees.

The finding of this study is consistent with the second hypothesis. This raises the question of what can explain the superiority of reading in the central visual field? The poorer reading performance of the peripheral retina may be related to a number of factors including

peripheral refraction errors, inadequate control of eye movements or changes in contrast sensitivity, temporal resolution, spatial acuity and cortical magnification factor with eccentricity.

The results of Hess et al. (1987) help eliminate a number of these possible explanations. Hess et al. (1987) measured scotopic contrast sensitivity, spatial and temporal resolution as a function of eccentricity and found them to be invariant with eccentricity from near the fovea out to 20 degrees. Consequently, these factors cannot explain the drop in reading rate. Investigation of the effects of peripheral refraction (Millidot, Johnson, Lamont & Leibowitz, 1975) have shown that the lower acuity of the peripheral is not a result of peripheral refractive errors. The results of Hess and his colleagues also reveal that the scaling of visual stimuli using cortical magnification factor for different retinal locations under scotopic conditions is not necessary since visual performance is constant out to about twenty degrees. This is consistent with the findings of Rovamo and Raninen (1990) which show that the scaling of a peripheral stimulus under scotopic conditions does not equalize visual performance across the retina but rather makes visual performance superior in the periphery.

It has been suggested (Cummings, Whittaker, Watson, & Budd, 1985) that inadequate control of eye movements when reading with the peripheral retina may account for the lower reading performance of the peripheral retina. This cannot, however, explain the present results because the need for eye movements was eliminated by presenting text serially in a fixed retinal location.

Under the present conditions it appears that the differences in reading performance between the central and peripheral retina is not a consequence of differences in spatiotemporal processing but rather a result of differences in the processing of information at points beyond the retinal level. It is likely that the reason that one reads best at or near the fovea when using exclusively rod vision may be a result of the same higher order mechanisms that account for the superiority of the fovea when reading under everyday visual conditions.

This conclusion is consistent with our present understanding of the neurophysiology of the rod pathway (see Daw, Jensen, & Brunken, 1990). Rod signals travel mostly independently from cone signals prior to the retinal innerplexiform layer and these signals are always transmitted through retinal ganglion cells through which cones signals pass. Thus rod signals would be expected to reach the same cortical structures and be processed in the same manner as those originating in cones.

At this time it is not known what specific mechanisms can account for the superiority of reading in the central retina but one can speculate that reading in the central retina may benefit from factors such as high receptive field density. One advantage of the high level of parallel processing like that found in the central visual field is rapid processing of visual information and resistance to noise in a stimulus.

The results of this study raise the question of why the foveal scotoma did not impair rod reading performance when subjects looked directly at the text? It has been found that the rod-free area is not necessarily concentric with the area of highest cone density (Curcio, Sloan, Kalina, & Hendrickson, 1990). Other studies have provided evidence of rod mechanisms in the foveal visual field (Stiles, 1946) and of rhodopsin at the point of fixation (Kilbride & Pori, 1989). These findings suggest that subjects may not have an absolute scotoma obscuring text at the point of fixation. In addition, the rod-free area is only about 1/4 of a degree wide. From personal observations it was found that the scotoma obscured only about 1/3 of a character.

The present findings suggest that the central visual field is necessary for rapid reading. Similar conclusion have been reached previously with regard to pattern recognition (Schlingensiepen, Campbell, Legge, & Legge, 1986) and reading under normal conditions (Legge, Rubin, Pelli, & Schleske, 1985; Turano & Rubin, 1988). The findings also suggest

that the proximity of the text to the central visual field is at least important as other factors such as contrast sensitivity, temporal resolution, and spatial acuity in determining the preferential locus for reading.

Figure 7. The relative locations of the fixation points in the stimulus display. Eccentricity values refer to the angular distance of the fixation stimulus from the center of the text. During actual testing, only one fixation stimulus was visible except when testing reading at 0 degrees when both the +5 and -5 degree fixation points were visible.

Figure 8. Plot of rod reading rate as a function of text presentation rate for text presented at five different eccentric viewing locations. The designated stimulus locations refer to the distance of the center of the text from the subjects' point of fixation, presumably the central fovea. Because the characters are not in a circular pattern about the fovea points to the left and right of center lie further from the fovea. In each case points furthestmost to the right and left of center lie approximately 5.25 degrees more peripherally than the center.

Figure 9. Maximum rod reading rate as a function of stimulus location. The maximum reading rate for each stimulus location was estimated from the peak of a curve fitted to the reading data for each condition in Figure 8.

Figure 10. Eye movement recordings showing how well a subject can maintain fixation during eccentric presentation of text. The top record illustrates our calibration procedure where the subject was asked to alternately fixate two points two degrees apart. The upward and downward arrows represent upward and downward saccades. The bottom two records illustrate the eye position during reading at five and twenty degrees of eccentricity.

CHAPTER III
COMPARISON OF ROD AND CONE READING PERFORMANCE
NEAR THRESHOLD

Introduction

A prerequisite for reading is that the eye transmit an adequate image of the text to the brain. Whether images that are adequate are necessarily equivalent has been the topic of investigations of Professor Gordon Legge and his colleagues (Legge et al., 1985a,b; 1987; Legge & Rubin, 1986; Rubin & Legge, 1989). In their studies, they show that reading performance is relatively unaffected by changes in a number of stimulus parameters including luminance contrast and wavelength. In the present study, we examine whether visual images produced by rod or cone photoreceptors would matter.

Rods and cone visual functioning differ in a variety of ways. The loss of color vision (Geldard, 1953), reduced acuity (Blackwell & Blackwell, 1961; Johnson, 1987), reduced contrast sensitivity (Daitch & Green, 1969), reduced temporal resolution (Hecht & Schlaer, 1936; Conner, 1982) and the presence of a scotoma (Geldard, 1953) are some of the notable characteristics of rod visual functioning.

Although the visual performance of the rod and cone visual systems differ it's difficult to predict whether reading with cone-mediated images will be superior to reading with rod-mediated images. Given the very modest conditions necessary for normal reading it's possible that the capabilities of rods may be sufficient to support rapid reading. The purpose of this experiment is to determine whether an observer's reading rate differs depending upon whether the image is generated by cones or rods.

Method

Subjects

Four of the subjects who participated in earlier experiments also participated in this experiment (see Chapters I & II). Subject S4 was unable to participate in this experiment.

Apparatus

Minor modifications were made on the apparatus for this experiment. The modification included the addition of a joystick input device. A blue filter (Edmund Scientific #866), and a red filter (#26) were used to produce rod- and cone-isolated test images.

Procedures

Alternative methods of determining reading rate were investigated in an ancillary experiment (see Appendix B). The method of adjustment was chosen for the present study as it was found to be the more efficient. The subjects' task was to find the highest rate of text presentation that they could read without skipping individual words. The initial rate of text presentation was randomly assigned by the computer and subjects used a joystick to vary the rate of text presentation. Upon finding the highest rate that they could read, the subjects were instructed to press a button on the joystick which ended the trial. The text presentation rate was subsequently printed on paper following the end of the trial. Subjects were given several practice trials before actual data collection began.

Psychophysical estimates of cone thresholds. Cone detection thresholds for text viewed eccentrically (5 degrees) were assessed using the traditional dark adaptation paradigm. Thresholds were measured using two methods.

The first method measured cone detection threshold as a function of time in the dark following a 3-minute bleach of the subjects right eye (see Figure 11). Subjects reported whether they could detect the presence of words in the window. If they could, the luminance

was decreased until the subject could not longer the text. The subject was asked to continue viewing the screen and to report immediately when they could first detect the words. The time from onset of dark adaptation to the moment when the subject reported detecting the words was recorded. The text luminance was again decreased until the subject could not detect its presence. The procedure was repeated until a total of 30 minutes had elapsed from the start of dark adaptation.

Cone thresholds were also measured using the method of limits. Each subjects' right eye was bleached and allowed to adapt for 5 minutes. Testing with the blue filter was limited to a maximum of 5 minutes following the adapting period. Testing with the red filter was limited to 10 minutes. The threshold estimates from the method of limits are indicated by the triangles in Figure 10.

Reading with the rods. Rod reading was tested following 30 minutes of dark adaptation. Reading was tested at .5, 1.0 and 1.5 log units above each subjects' rod detection threshold. The order of testing was random.

Reading with the cones. Most of the results for cone reading were obtained using the red filter. Cone reading was tested at 0.5, 1.0 and 1.5 log units above the subjects' psychophysical cone threshold. The reading tests were conducted during the cone plateau phase of the dark adaptation curve following the 3-minute bleach. Only reading rates between 5 and 13 minutes were recorded. In order to collect sufficient data, the subjects' eye had to be bleached a number of times. In a control experiment, we also examined cone reading using the blue filter during the period from 5 to 9 minutes. The results (Figure 11) were consistent with our expectation and the results of Legge and Rubin (1986) which show that the wavelength of the text does not have a significant effect on reading performance.

Results

Psychophysical Results

Thresholds for both red and blue reached a plateau after the initial 5 minutes. The length of the plateau, however, was considerably longer for the red stimulus. The plateau lasted approximately 12- to 14-minutes after which a decrease in sensitivity attributable to the rods followed. For the blue stimulus the cone plateau lasted only about 5 minutes. It is only during the 5-minute cone plateau for blue and the 12- to 14-minute plateau for red that cone mediated reading could be isolated

The psychophysical results justify the decision to measure rod reading with the blue filter and cone reading with the red filter. With the blue filter, rod vision can be isolated for luminances as high as 2.0 log units above absolute threshold. With the red filter, cone vision can be isolated up to 1.5 log units above the cone plateau.

Reading Performance

Individual subject rod and cone data are shown in Figure 13. In general, the reading rate for cone vision was greater than for rod vision (Figure 14). A repeated measures analysis of variance (Kepple, 1982) using log reading rates (see Table 1) showed that there was a significant main effect of receptor type ($F(1, 2) = 10.88, p < .05$) as well as luminance ($F(3, 3) = 35.93, p < .05$). The interaction between receptor type and luminance was not significant ($F(2, 6) = .91, p > .05$).

Discussion

The results show that observers read faster when the text images are cone-mediated. The results have relevance to those of D'Zmura and Lennie (1986). D'Zmura and Lennie (1986) found that there is equivalence between low spatial frequency images generated by the rods and those generated by the cones near threshold. Observers were unable to perceptually

distinguish between the two images. D'Zmura and Lennie (1986) explained this finding in terms of the afferent signals to retinal ganglion cells. Rod signals do not travel to the brain via special ganglion cells. Rather the rod signals travel through pathways shared with cone signals (Daw, Jensen, & Brunken, 1990). Accordingly, for certain stimulus conditions, the brain has no basis of knowing whether the visual signals originated in rod or cone photoreceptors.

These results do not necessarily contradict those of D'Zmura and Lennie (1986). When viewing the rod- and cone-isolated text at 5 degrees eccentricity, we can appreciate the previous findings. The rod and cone images do appear to have the same spatial quality. The finding that the observer reads more rapidly with cone-generated images probably relates to some other factor.

One possible explanation deals with the higher temporal resolution capacity of the cone pathway (Conner & MacLeod, 1977; Hecht & Schlaer, 1936). Cones respond rapidly to stimuli reaching their peak response amplitude shortly after onset of the stimulus. Their response also decays rapidly after termination of the stimulus. In contrast the rods response takes longer to reach peak amplitude and decays more slowly than that of the cones (Whitten & Brown, 1973). These differences are likely to have a number of perceptual effects. The slower response of the rods restricts the temporal resolving capacity of the system. In addition the slower decay of the rods is also likely to have detrimental effects due to after-images resulting from the slow decay response of rods. These after-images would tend to mask stimuli presented shortly after the first.

Another possible explanation might have to do with the ON- and OFF- nature of different visual pathways. Rod signals pass through sign-inverting bipolar cells and contribute mainly to the ON-center ganglion cells (Daw, Jensen, & Brunken, 1990). Cone signals, on the other hand, pass through both sign-conserving and sign-inverting bipolar cells and contribute to both ON- and OFF-center ganglion cells. As there appears to be equal number of ON-

and OFF-center ganglion cells, there may be a greater number of ganglion cells that transmit the cone images to the brain. However, it is important to point out that at the present time we have a poor understanding of the need or purpose of having ON- and OFF-center ganglion cells (Schiller, Sandell, & Maunsell, 1986).

Differences in the observed rod and cone reading rates are not likely to be a result of the particular choice of text size; that is, selected to favor the high spatial resolution cone pathways. According to D'Zmura and Lennie (1986) two visual pathways can be distinguished, one a low spatial resolution pathway in which both rod and cone signals can pass and higher spatial resolution pathway in which only cone signals pass. The critical spatial frequency content of the text we used (as computed in accordance with Legge, Rubin, Pelli and Schleske, 1985) lies between 0.31 and 0.62 cycles per degree. This frequency range is much lower than the high spatial frequencies which can only be detected by the cone-exclusive pathway. The spatial frequency content of the text lies well within the spatial frequencies detected by the rod-cone pathway.

The finding that an observer reads cone-generated images faster than rod-generated images has implications for the role of the fovea in reading. There are probably many factors underlying the capability of the fovea to support rapid reading. To this date, little if any attention has been paid to understanding the contribution that the photoreceptor themselves might play. Variation in the distribution of different photoreceptors across the retina is significant. The photoreceptors with the highest temporal resolution, i.e., the long and middle wavelength sensitive cones, are found in highest density in the very center of the fovea. The short-wavelength-sensitive cones which are relatively more sluggish have peak density distribution at about .75-1.5 degrees of eccentricity (de Monasterio, McCrane, Newlander, & Schein, 1985). The most sluggish photoreceptors, the rods, of course have highest density at about 15 degrees eccentricity (Curcio et al., 1990). The results of our experiment suggest that,

at least, part of the reason why the fovea supports rapid reading concerns the type of photoreceptors mediating the fovea.

It is also worth noting that at the retinal eccentricity tested in this experiment, the density for the rods is about 60,000 whereas for the cones it is about 16,000 photoreceptors per square millimeter (Curcio et al., 1990). If another retinal region had been selected for this experiment, the superiority of the cones probably would have been even more apparent.

Table 1

Analysis of variance source table for the variable reading rate as a function of receptor type and luminance level for text presented five degrees in the inferior retina.

<u>Source</u>	<u>df</u>	<u>SS</u>	<u>F</u>	<u>p</u>
Subject (A)	3	3.04	.	.
Receptor (B)	1	5.07	35.93	.0093
Trial (C)	4	.15	.89	.5014
Luminance (D)	2	20.90	10.88	.0101
A*B	3	.42	.	.
A*D	6	5.76	.	.
A*C	12	.51	.	.
B*D	2	.26	.91	.4526
B*C	4	.38	.84	.5281
C*D	8	.49	1.29	.2967
A*C*D	32	1.63	.	.
A*B*D	6	.85	.	.
B*C*D	16	1.09	.60	.2191
A*B*C	12	1.37	.	.
A*B*C*D	16	.74	.	.
Total	119	42.19

Figure 11. Estimates of cone detection thresholds made using two psychophysical methods and chromatic filters. The first technique (represented by the square symbols) was used to measure cone detection thresholds as a function of time in the dark. The triangles represent cone detection thresholds measured during the cone plateau phase of the dark adaptation curve using the method of limits. The open and closed symbols represent cone detection thresholds measured using either a red or blue chromatic filter, respectively. The dash lines show approximately where rod thresholds would lie if they could be measured above cone threshold.

Figure 12. Comparison of cone reading rate for photopically isoluminant red and blue text. Reading was tested half a log unit above cone detection thresholds and the text was positioned 5 degrees below the point of fixation. The diagonal line represents the locus of points having identical reading rates under both conditions.

Figure 13. Rod and cone reading rates as a function of log text luminance for four subjects. The rod reading rates were obtained for text viewed through a blue filter. The cone reading rates were obtained using a red chromatic filter.

Figure 14. Mean ($n=4$) rod and cone reading rate as a function of log text luminance. The brackets are the 95% confidence limits for rod and cone reading rate at each luminance level.

CHAPTER IV

CONCLUSIONS

The results of the experiments discussed in Chapters I, II and III, lead to a number of conclusions about rod reading and the effects of luminance, comparison to cone reading, and the effects of retinal location.

Reading is not an exclusive property of the cone visual system. Subjects can read even with an image available through the night vision system. Comparisons of rod and cone reading suggest that cone vision allows an observer to read faster than the rod visual system.

Whether reading with the rods or cones, performance of both day and night vision is dependent on the specific luminance level. Subjects' reading performance were found to improve rapidly with luminance at low luminance levels and to plateau once cone thresholds were exceeded.

The results also show that reading is greatly dependent on where in the visual field the text is presented. Subjects can read using the peripheral retina, however, reading performance is much poorer in the peripheral visual field than in the central visual field. This is true even though the subjects had a central scotoma.

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APPENDIX A

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APPENDIX A

EXTENDED LITERATURE REVIEW

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Observation; ...
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visual system is ...

Chlorophyll System in the Dark

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Existing Literature on Reading with the Rod Visual System

Little, if any, material exists in the available literature regarding the properties of the reading ability of the rod visual system. There may be one exception. In a previous study (Legge & Rubin, 1986) concerning the effects of wavelength, reading was studied under very low illumination levels. The authors concluded that humans can read with scotopic vision; although, no rigorous attempt was made to exclude the possibility that the cones, at least in part, contributed to the reading.

The Duplex Nature of Human Vision

Humans, like primates and a number of other animal species, have a visual system which mediate night (i.e., vision under moonlight illumination) and day (vision under sun light illumination) vision. The Duplex Theory of vision holds that night and day vision are mediated by different parts of the visual system. Night vision is mediated by the rod photoreceptors and neurons through which rod signals pass. Day vision is mediated by cone photoreceptors and the neurons through which cone signals pass. The duplex nature of our visual system is evidenced in both the psychophysical and physiological research.

Psychophysical Evidence for the Duplex Nature of Vision

Dark adaptation. Dark adaptation curves provide evidence of a duplex visual system. The dark adaptation curve graphically represents the increase in sensitivity of the visual system as a function of time in the dark. The unique aspect of the dark adaptation curve is that it is composed of two parts. The first part of the dark adaptation curve is characterized by a rapid initial increase in sensitivity (about 2 log units) which plateaus after about 5 minutes. The initial drop in threshold and leveling off of sensitivity is followed by another rapid increase and leveling off of sensitivity. Peak sensitivity is reached after about 30 to 40 minutes in the

dark but can vary depending on the duration and brightness of a preadapting stimulus.

Sensitivity may increase by a total of five log units depending on the specific experimental conditions (Wyszecki & Stiles, 1982).

There is strong support for the conclusion that the dark adaptation curve is produced by the activity of two separate systems. For example, when a small test field is restricted to the fovea only the initial drop and plateau of sensitivity is observed (Hecht, Haig, & Wald, 1935). Hecht and Hsia (1945) studied the time needed to reach final threshold following preadaptation to different wavelengths. They showed that threshold is reached more quickly when the preadapting stimulus was of a long wavelength (to which the rods are insensitive) than when it was of a short wavelength (to which the rods are sensitive).

Spectral sensitivity. The spectral sensitivity curves for the rod and cone systems are obtained by determining the minimum illumination of various wavelengths required for detection (Wald, 1945). The most prominent feature of rod and cone spectral sensitivity is that it varies as a function of wavelength. Rod spectral sensitivity peaks at a wavelength of about 505 nm whereas the sensitivity of the photopic system is greatest for a wavelength corresponding to about 555 nm. The absolute sensitivity of the scotopic system is greater for all wavelengths of visible lights except very long wavelengths (above 650 nm) where cone sensitivity is slightly higher.

Purkinje shift. The Purkinje shift provides further proof of a duplex visual system. The name refers to the perceived change in the brightness of various colors with adaptation level. When an observer who is adapted to low illumination views a red colored object under low illumination it will appear less bright than when its viewed under high illumination conditions. The opposite is true for blues. The perceived changes in brightness of different chromatic stimuli is a result of the shift in spectral sensitivity which occurs when vision transitions from cone to rod or vice versa. Since the rods are relatively insensitive to reds and

very sensitive to blues, a red will appear dimmer than a equally intense blue. The opposite is true when observers go from seeing with the rod system to the cone system.

Contrast sensitivity. The photopic and scotopic system also differ with respect to their contrast sensitivity. An observer with the rods visual system can detect contrast differences as small as 2% (D'Zmura & Lennie, 1986) for spatial frequencies of about .92 cpd. The contrast sensitivity of the photopic is about a factor of 10 lower than that of the scotopic system for spatial frequencies of about 3-5 cpd.

Eccentricity. Human vision is most acute when observers are functioning under photopic conditions and using the fovea to fixate the stimulus. Motion perception (Johnson & Leibowitz, 1974), acuity (Johnson, 1987), detection (Johnson, Keltner, & Balestrery, 1978, 1981) and contrast sensitivity (Koenderink, Bouman, Bueno de Mesquita, & Slappendel, 1978) all peak at the fovea and decrease with eccentricity.

At scotopic luminance levels the midperiphery becomes more sensitive than the fovea. Detection thresholds are lowest at about 15 to 20 degrees in the peripheral retina (Sloan, 1950) whereas contrast sensitivity, spatial and temporal resolution are constant from the fovea to about twenty degrees (Hess, Nordby, & Pointer, 1947).

Spatial vision. Measures of scotopic visual acuity (Johnson, 1987) show that it is significantly worse than that of the photopic system (i. e., between 20/80 and 20/125). As noted earlier photopic visual acuity is highest at the fovea where the greatest concentrations of cones is found whereas the acuity of the scotopic system is invariant from near the fovea to about 20 degrees (Hess et al., 1987).

Temporal resolution. Additional support for the distinction between scotopic and photopic systems is found in studies of the temporal response of the visual system. The temporal response of the visual system is studied using Critical Flicker Fusion (CFF). The maximum flicker rate increases with illumination but plateaus at about 15 hz under rod mediated conditions (Hecht & Shlaer, 1936). At higher cone illumination levels the temporal

resolution of the visual system increases to a maximum flicker rate of 50 hz (Hecht & Shlaer, 1936). Using techniques to isolate rod responses at high luminance levels Conner and MacLeod (1977) has shown that rods can detect flicker frequencies as high as 28 hz.

Stiles-Crawford effect. Another functional difference between the rod and cone system is the differences in sensitivity which the two systems show to light which strikes the photoreceptors at oblique angles (Stiles, 1939). The Stiles-Crawford effect refers to the observation that the cones show variations in sensitivity depending on the angle at which incident light strikes them. For example, a thin beam of light entering the eye near the edge of the pupil and striking the same photoreceptors as a light (of the same brightness) entering through the center of the eye will appear dimmer. These findings suggest that cones are more effective at capturing light that strikes the photoreceptor head on. The rods system has not been shown the high degree of directional sensitivity of the cones.

Physiological Research

Photoreceptors. Research has shown that the photoreceptors mediating night vision, (i.e., the rods) and those mediating the cones differ in a number of ways. There are a number of morphological differences among which the most commonly noted one include the shape of outer segments. The outer segments of most cones (especially those outside the fovea) are conical. Those of rods are cylindrical.

The number and distribution of these photoreceptors are significant. There are approximately 92 million rods and 4.6 million cones (Curcio, Sloan, Kalina, & Hendrickson, 1990) distributed throughout the human retina. Their respective distributions varies greatly with eccentricity.

Cone density is greatest at the fovea (between 100,000 to 324,000 per mm²) and decreases sharply with eccentricity (Osterberg, 1937; Curcio, Sloan, Packer, Hendrickson, & Kalina, 1987; Curcio, Sloan, Kalina, & Hendrickson, 1990). The cone density profile plateaus

at much lower values beyond ten degrees. It also appears that the concentration of cones is not radially symmetrical (Curcio et al., 1987) and are more densely packed in the nasal retina than in the temporal retina.

Rod photoreceptor density also varies with eccentricity with the peak occurring at about 20 degrees nasally and temporally. No rods are found in the center of the fovea and no cones or rods are found in the optic disk (i.e., blind spot).

Neural pathways for rods and cone signals. Retinal ganglion cells have been classified by a number of different criteria. Currently, there is much interest in understanding the functional characteristics of ganglion cells that terminate in the magnocellular layer (i.e., M-cells) versus those that terminate in the parvocellular layer (i.e., P-cells) of the lateral geniculate nucleus (Kaplan & Shapley, 1986). Additionally, ganglion cells can be classified morphologically (alpha, beta, gamma, etc), by their conduction velocity, or by their receptive field characteristics. With regards to the latter, ganglion cells can be classified on the basis of whether they have ON- or OFF-center responses, whether they are color-opponent, or whether they have a sustained or transient response pattern. Recent evidence suggest that rod signals travel exclusively through ON-center ganglion cells. Purpura, Kaplan and Shapley (1988) studied M and P cell response to contrast at low luminance levels and found that at some low luminance levels that only M cells respond to contrast differences. At slightly higher luminance levels both P and M cells respond to contrast differences. This finding would suggest that at low luminance levels that only the M cells may contribute to a visual image. Fairchild and Lennie (1988), however, found that the highest spatial frequency that could be resolved in the peripheral retina under scotopic conditions was greater than that which could be supported by the M ganglion cells. The exact nature of the relationship between rods and the M and P ganglion cells is not at this time clear.

Rod and cone pathways have also been found (reviewed in Daw, Jensen, & Brunken, 1990) to differ in more specific ways. Cones depolarize in response to light and send signals

across synapses to either a depolarizing or hyperpolarizing cone bipolar cells. The depolarizing and hyperpolarizing cone bipolar cells in turn are connected to ON-center and OFF-center ganglion cells. Rods photoreceptors are unique in that connect to a single type of bipolar cell (e.g., rod bipolar cell) which unlike cone bipolar cells connects to a rod ammercrine. The rod ammercrine cell in turn connects to both ON- and OFF-center ganglion cells. While the rod ammercrine cell has an excitory effect on the ON-center ganglion cells it inhibits OFF-center ganglion cells. This would seem to suggest that rod have access to only part of the optic pathway and that signals travel to the lateral geniculate nucleus by way of the ON-center pathway. There is a secondary rod pathway which is active at mesopic luminance levels. Rod signals can travel through cone bipolar cells as a result of gap junctions made by cones on rod photoreceptors.

Psychophysical and anatomical evidence supports the contention that rods signals may be found in only part of the visual pathway. All ganglion cells which receive rod input also receive input form cones the opposite is not, however, true. D'Zmura and Lennie (1986) found that under conditions that isolate the rods that rod spatial acuity is lower than that of cones under cone isolating conditions. On the basis of this finding and other evidence they have argued that the most parsimonious conclusion is that rods have access to only part of the visual pathway. The difference in spatial acuity they argue is a result of rods having access to ganglion cells sensitive to low and middle spatial frequencies which also receive input form cones at higher luminance levels. The cones in addition have access to ganglion cells sensitive to high spatial frequencies.

The above picture though somewhat confusing is not necessarily in conflict. The optic nerve exiting the eye is composed M and P cells. Rod signals are found in both M and P though the findings of Purpura, Kaplan and Shapley (1988) would suggest that at some luminance levels rod signals may only be found in the M type cells. Both ON- and OFF-center types cells are found in both the M and P type cells. Anatomical evidence supports the

contention that at low luminance conditions rod signals are conveyed to the ON-center ganglion cells by excitatory effects of the rod ammercrine cells which at the same time inhibit the response of OFF-center cells. The implication of the findings of D'Zmura and Lennie is that rod signals are conveyed along a portion of the ON-center P and M ganglion cells which receive both cone and rod input and which are sensitive to middle and low spatial frequencies.

Review of the Literature on Reading

The literature on reading is quite extensive and selective parts of this literature have been reviewed by a number of authors. Perceptual and cognitive aspects of reading were recently reviewed by Pollatesk (1989) and Just and Carpenter (1980). The effects of stimulus factors including luminance, character size, type, etc., have been reviewed by Boyce (Chapt. 4, 1981), Tinker (1963), Crook (1949) and Luckiesh (1944). Many of the early studies on reading investigated the effects of a number of factors including lighting levels and stimulus characteristics such as contrast, type size, type style on reading performance.

One of the primary concerns of the early work was determining the appropriate illumination levels for various tasks including reading (Luckiesh & Moss, 1935; Luckiesh, 1944; Tinker, 1939; Rose & Rostas, 1951). Investigation of this issue continues to this day as evidenced a number of recent articles on the subject (Knave, 1984; Rogers, Spiker, & Cicinelli, 1986; Smith & Rea, 1978; 1982).

The early work of Luckiesh and Moss (1935) and Tinker (1939) and the subsequent work of Smith and Rea (1978, 1982) and Legge et al. (1985a) have shown that illumination has relatively little effect on reading over much of the photopic range of illumination. Legge et al. (1985a) found that reading rate increased a total of 80 wpm when luminance was varied over a three log unit range (.3 to 300 cd/m²). The combined effects of illumination and print quality, however, are important determinants of the performance of older subjects and to a lesser extent young subjects (Smith & Rea, 1978).

One of numerous typographical factors investigated by researchers was the effect of type size (Paterson & Tinker, 1929). Paterson and Tinker (1929) found the optimal type size to be between 8 and 10 point type (1 point=.35mm). However, because viewing distance was not controlled the angular subtense of the text is not known. Recently, Legge et al. (1985) studied the effects of text size on reading and found reading performance to be superior with text subtending 0.3 to 2 degrees.

Contrast is another factor which has received considerable attention. The general conclusion of the early work in the area was that contrast has little effect on reading performance, however, this conclusion was questioned because the range of contrast tested was often very restricted (Luckiesh & Moss, 1938, 1941). Recently, Legge, Rubin, and Luebker (1987) investigated the effects of contrast on reading. In this study contrast was varied over a large range of contrast values ranging from .01 to 1.0. Legge et al. (1987) concluded that contrast has little effect over a broad range of text size and contrast levels. The effects of contrast become evident only when contrast is very low (less than .1) and the text is either very small (less than .2 degrees) or very large (greater than 2.0 degrees). These findings show the remarkable tolerance that human vision has for changes in illumination, contrast and character size.

Legge et al. (1985a, 1987) have also shown that the necessary information for reading lies in a one octave band of spatial frequencies extending forward from the fundamental spatial frequency (the inverse of the center to center spacing of text in degrees) of the text. The requirements for reading appear to be rather modest. This finding suggests that a subject would be able to read as long as the critical spatial frequencies lie within the range of spatial frequencies the subjects is sensitive to and that there is sufficient contrast such that they can be discriminated.

There has been some concern whether stylistic differences of typefaces may affect reading performance (Tinker, 1963; Luckiesh & Moss, 1937; Poulton, 1965). Like the findings

for illumination the research suggests that there are little if any effects of typeface on reading performance when the quality of the print is good.

Some have questioned whether there is any beneficial effect of printing text entirely in upper or lower case characters. Text typed in lower case was read more quickly than (Tinker & Paterson, 1928; Breland & Breland, 1944; Poulton, 1968) text typed in upper case. Recent findings (Kember & Varley, 1987) suggest that the above findings may apply to conditions where subjects are reading text off paper and not in the case where subjects are required to read text on a video display terminal (VDT). Kember and Varley (1987) compared reading off paper versus reading off a VDT using all upper or lower case type. They found no difference between text presented all in upper case or lower case in terms of the number of errors made by subjects reading text off a VDT. They did find that upper case letters were easier to identify than lower case letters when presented individually.

Recent research on reading has focused on the role of perceptual factors in reading. Rayner and Bertera (1979) investigated the role of peripheral vision in reading by using windows which restrict the peripheral vision. Under these conditions they have found that reading speed increases with window size up to a maximum width of about 25 to 29 characters. These findings are in conflict with others that have shown little improvement with window widths exceeding four characters (Cattell, 1886; Legge, Pelli, Rubin, & Schleske, 1985a; Legge, Rubin, Pelli, & Schleske, 1985b).

Legge et al. (1985a,b) have argued that the difference may be due to the fact that in normal reading information in the periphery is used to program saccades and fixations. Consequently, larger window may facilitate reading by allowing saccades and fixations to be program. Under the conditions used by Legge et al. (1985a,b) and Cattell (1886) reading rates did not improve with larger windows because the window boundaries served as a reference point for the return saccade after the subject had followed the text through the window.

With the proliferation of computers there has been an increased interest in whether it is easier to read text that is white printed on a black background or vice versa. Tinker (1963) and others (Legge et al., 1985a,b, 1986) found little or no differences in reading performance of normal subjects in the two conditions. This is not true for subjects with certain types of visual disabilities which read faster under the reverse polarity condition, i.e., white text on black or dark background (Legge et al., 1985b).

Review of the Literature on Reading Performance with Visual Disabilities

Cataracts, clouding of ocular media, and loss of visual field can produce severe deficits in visual functioning. These effects are manifested in a variety of ways including changes in the patterns of eye movements. A number of researchers (Whittaker, Budd, & Cummings, 1988; McMahon & Hansen, 1988; Bertera, 1988) have shown that the loss of part of the visual field can produce concomitant changes in fixation duration, number of fixations, search time, and in saccade accuracy.

The effects of visual disabilities are also evident when the vision of subjects is assessed using common vision tests. Subjects show increased contrast thresholds (Marron & Bailey, 1982; Bailey, 1987) and lower visual acuity (Marron & Bailey, 1982). The impairment of visual function produced by loss of part of the visual field is readily apparent in visual exams and in the ability of subjects to do real world tasks such as to navigate about their environment (Marron & Bailey, 1982; Pelli & Serio, 1984) and in their ability to reading (Timberlake, Mainster, Peli, Augliere, Essock, & Arend, 1986; Timberlake, Peli, Essock, & Augliere, 1987; Legge et al., 1985a,b; Krischer & Meissen, 1983).

Legge et al. (1985a,b) studied effects of stimulus characteristics on the reading performance of both normal and low vision patients. The dichotomy of intact central fields versus restricted visual field and whether patients had cloudy versus clear ocular media were

found to be significant predictors of reading performance. The average reading rate for patients with central field loss or intact central fields was 25 and 125 words per minute, respectively. These reading rates are significantly lower than those obtained for normal subjects.

Another significant predictor of reading performance was character size. Patients with intact central fields read faster with intermediate sized characters with the peak corresponding to characters subtending 3 to 6 degrees. Patients with central field loss benefitted from increasing magnification even up to the limits of the display used by Legge et al. (1987). Another interesting finding was that patients with cloudy ocular media performed better on the reading task when text was presented under the reverse polarity condition. Normal subjects and subjects with clear ocular media showed no improvement under this condition.

The literature on reading is quite extensive and thus many topics are not reviewed here. Some of the research areas not reviewed include the role of eye movements in reading (Bouma & De Voogd, 1974; Rayner & McConkie, 1976; Kowler & Anton, 1987; Poulton, 1962), cognitive aspects of reading (Pollatsek, 1989; Inhoff & Rayner, 1980;), models of reading (Just & Carpenter, 1980; Daneman & Carpenter, 1980), differences between reading from paper versus VDT (Gould, Alfaro, Barnes, Finn, Grischowsky, & Minuto, 1987) effects of other stimulus factors like the effect of line length, formatting issues, etc. (Paterson & Tinker, 1942, Tinker, 1963) and many other areas.

Psychophysics of Reading

Only recently has there been an attempt to study reading psychophysically. In a series of papers, Legge et al. (1985a,b, 1986, 1987) reported on the effects of numerous factors on reading performance of both normal and visually impaired subjects. Besides the important findings which in many cases extended the work of earlier researchers Legge et al. (1985a) also made an important methodological contribution.

The methodology developed by Legge et al. (1985a,b) gives the experimenter easy control over experimental manipulations and an easily obtained dependent measure. The advantage of Legge's method is that it is purely a measure of performance. In this case it is a measure of peak reading rate. It does not have the drawback of a number of other performance measures which attempt to account for both comprehension and reading rate. These measures force the reader to make a trade-off between reading rate and understanding what they read. Other dependent measures like reading errors tend to be rather insensitive measures because subjects tend to make few errors when reading.

To determine reading performance Legge required subjects to read aloud text which scanned from right to left through a window on a television screen. The text was presented at different rates but during any given trial the text scan rate was constant. Reading performance was determined by multiplying the scan rate (in words per minute) by the subject's accuracy. Accuracy was expressed in percent of the words which were correctly identified.

Legge plotted reading rate versus scan rate on a logarithmic scale as shown in Figure 4 in Chapter I. If a subject is able to read all the words presented at some given scan rate then the point will lie along the diagonal line. Legge found that there is a very sharp transition from approximately perfect reading to ineffective reading as the scan rate of the text was increased. Legge defined maximum reading rate as the peak of the function like the one shown in Figure 4 (Chapter I). To estimate the effects of various factors on maximum reading rate the investigator simply has to find the transition point from errorless to ineffective reading for various conditions.

APPENDIX B

EVALUATION OF ALTERNATIVE METHODS FOR

ESTIMATING READING PERFORMANCE

Introduction

In the initial explorations of rod reading we used a method developed by Legge et al. (1985) to estimate reading rate. This method which we refer to as the standard method was found to be very time-consuming under the experimental conditions we employed. The purpose of this experiment was to evaluate several new methods as possible alternatives to the standard method. Each of the new methods was evaluated on a number of criteria. The different criteria included reliability, precision, validity, and the degree to which the new method biased read rates by providing rates which are higher or lower than those of the standard.

Method

Subjects

Five graduate students from the Texas Tech psychology department participated in the study. All five normal subjects were reportedly correctable to 20/20 visual acuity and were in good health. All of the subjects were found to have normal night vision thresholds.

Apparatus

The apparatus was the same as used in earlier experiments.

Criteria for Comparison of Alternative Methods

A number of criteria were used in selecting one of the methods. We wanted a method that had both high accuracy (i.e., precision) in measurement and good predictive validity. By this we mean that the reading rates obtained with the new methods were significantly correlated with the subjects performance on the standard test (original method). Additionally, we wanted a method that was faster (i.e., more efficient) than the standard method.

Description of Different Methods

Standard method. The standard method refers the method developed by Legge et al. (1985) which is described fully in Chapter I.

Method of adjustment. This method allowed subjects to vary the rate of text presentation by using a joystick. Each subjects was initially shown serially presented text at a rate randomly set by computer. Each subject was instructed to use the joystick to find the highest rate of text presentation that they could read without skipping individual words and to press a button on the joystick once they had done so. Subsequently, the computer printed out the rate of text presentation selected by the subject.

The text consisted of 50 four-letter words randomly selected by the computer from pool of 300 words. The text was continuously presented until the subject found the highest rate of text presentation that they could read. The words in the pool were selected from a list of the most frequent words used by college students (Black, Stratton, Nichols, & Chavez, 1985).

Method of limits. In this method the subject was presented text in one of two ways. The initial presentation rate of the text was either very slow and then steadily increased (acceleration mode) or the text was presented at a high rate which then decreased (deceleration mode). In each of these cases the text was scanned from right to left across an eight-character wide window. To determine the reading rate in the acceleration mode we first identified the point where the subject made two consecutive errors. This was done by comparing a recording of the subject reading the text aloud and a hard copy of the actual text presented to the subject. The rate at which different words in the string were presented was known from prior calibrations. The rate of presentation of the first word of the two consecutive errors was taken as an estimate of the subjects reading rate.

In the deceleration mode text was initially presented at a high rate and then was steadily decreased. Reading rate was estimated from rate of presentation of the first word of

two consecutive words the subject was able to identify correctly. The mean of the reading rates obtained from the acceleration and deceleration mode estimates was taken as an estimate of the peak reading rate.

Procedure

Prior to testing subjects were given instructions and a 20- to 30-minute practice session. Following the initial practice session the subjects were dark adapted for at least 30 minutes and again allowed to practice under low illumination for 15 to 20 minutes. At the start of each trial, a GET READY... message was presented on the screen to help prepare the subject for the oncoming text. The subject was permitted to view the text in whatever manner he wished as long as he fixated somewhere within the confines of the window as indicated by four orientation dots.

The reading results used to compare the methods were obtained for three luminance levels corresponding to -3.88, -3.38, and -2.88 scotopic Ft-L. Reading was tested five times at each of conditions for each of the methods. The testing session lasted between 2 and 4 hours.

Results

Measure of Predictive Validity

The predictive validity of each of the methods was calculated by determining the value of r^2 for the correlation between the reading rates obtained using the standard method and each of the new methods. The value of r^2 gives us a measure of the proportion of variance in the standard test that is accounted for by variance in the new method. Ideally one would seek an r^2 value as close to one as possible. This would allow the experimenter to predict the performance of the standard test with a high degree of accuracy. Correlations of $r(3) = .64$, $p > .05$ and $r(3) = .65$, $p > .05$ with r^2 values of .41 and .42 for the method of adjustment and method of limits were obtained, respectively. Neither of the correlations was significant.

Precision

To estimate the precision of our methods the average variance for the five replications at each of the luminance levels was calculated. This was done by calculating the average variance for five subjects due to replications ($n=5$) at each luminance level. The value of this calculation was an estimate of the measurement error variation which assess the precision of the technique for measuring reading rate. The following table lists the total variance attributable to replication for 5 subjects for the method of adjustment and the method of limits at each of three luminance levels. One can see that the method of adjustment has the lowest values across all the luminance levels where reading rates were obtained.

	Luminance level (Scotopic Ft-L)		
	-3.88	-3.38	-2.88
Method of limits (variance)	.489	.099	.285
Method of adjustment (variance)	.068	.028	.047

Efficiency

The time required to get a set of data from a subject was used to estimate the efficiency of the methods. The method of adjustment was the most efficient taking about 5 to 6 hours to obtain a set reading rates. This was better than the original, and the method of limits which took approximately 10 to 15 hours, and 10 hours, respectively.

Discussion

On the basis of the evaluative results the method of adjustment was chosen to be used in future experiments. This method proved to be superior in both its precision and efficiency. Neither method was found to be valid. This is likely the result of the few subjects from whom data was collected on all three methods (i.e., 5). Under such conditions the correlation coefficient necessary for significance is very stringent (i.e., greater than 0.80).

APPENDIX C
COMPUTER PROGRAMS USED TO PRESENT TEXT.

```

1  REM -----
2  REM PROGRAM TITLE: SCAN/V2. TEXT SCANNING METHOD
3  REM THIS PROGRAM PRESENTS TEN RANDOMLY SELECTED
4  REM WORDS AND SCANS THEM FROM RIGHT TO LEFT ACROSS
5  REM AN EIGHT CHARACTER WIDE WINDOW. THE PROGRAM
6  REM WAS WRITTEN FOR A TRS-80 MODEL I COMPUTER.
7  REM THIS PROGRAM WAS USED IN THE FIRST EXPERIMENT
8  REM STUDYING ROD READING.
9  REM -----
10 CLEAR 5000
40 B=8:T=480:Z$=" GET READY ...."
50 DIM S$(100,2)
60 PRINT CHR$(23)
80 CLS
81 REM -----
82 REM SET OF TEXT USED TO GENERATE THE STRINGS
83 REM PRESENTED TO THE SUBJECTS.
84 REM -----
100 S$(1,1)=" HARM SLID NICK ZEAL REEF KNIT PUSH MYTH WAIT LION "
101 S$(2,1)=" YOUR WARN FIVE MOOD EDGE ROSE STEM HELM HELD VASE "
102 S$(3,1)=" FLAG VERY VEST JUST EACH GOLF SOFT HOME SEEM VIEW "
103 S$(4,1)=" SOME EVER VOTE BACK HARD UNDO LIKE IDEA UPON SAME "
104 S$(5,1)=" EASY PART WORK ALSO WENT THEM PEAT JUNK SICK MINK "
105 S$(6,1)=" OVER YEAR LOOK SHOT HINT AWAY OVEN ROLE REAL SHIP "
106 S$(7,1)=" MOST LEAD HOUR GOAL TEST CAMP NEST DAWN TIME BOTH "
107 S$(8,1)=" WITH WIPE TOLD EASE YARD RISK GOOD LAST REST LEFT "
108 S$(9,1)=" RICH CALL EVEN PLAN GIVE ONCE SIGN SENT ONLY OPEN "
109 S$(10,1)=" CODE RUST POST ELSE BEAR LINK SAID RIPE NEED PLEA "
110 S$(11,1)=" PARK NEWS THEN LOCK FACT DOWN WHEN BASE BEST TORN "
111 S$(12,1)=" MANY COME DARK PLUG FOUL HOLE HELP INTO SELL BEEN "
112 S$(13,1)=" TERM STOP SEND BILL TRUE KIND CASE DOES GOES RACE "
113 S$(14,1)=" REAP LAID PURE TALK DRUG STAR HAVE RUSH THAT MUCH "
114 S$(15,1)=" KILL GIFT MASS TREE THEY BONE DEAL DIRE BOUT THIS "
115 S$(16,1)=" MOVE GAIN WERE LOAD HUNT MIND GANG BOMB TEST FULL "
116 S$(17,1)=" FORM WORD GAME TOOL HAND GAVE JAIL NOTE IRON BOOK "
117 S$(18,1)=" TENT FROM JOIN CARE RANK BUMP CAME FEEL KNOW GRAB "
118 S$(19,1)=" MAKE TELL VARY FELT DONE LORD HIGH LONG SHOW ARMY "
119 S$(20,1)=" SUCH BELL VICE PAST AIDE KEPT NONE KEEP LOVE POUR "
120 S$(21,1)=" GRIP COST GRIN PUNT MAIL SALE FILL PLUS MISS BLOW "
121 S$(22,1)=" ARMS FREE KING COAT LIVE MEET BELT CASH GURU MADE "
122 S$(23,1)=" KNEW NAIL SOAP NAVY EXIT AREA MEAN FIRE MORE BALD "
123 S$(24,1)=" TAKE CULT POOR CORE SURE SLIM FEAR TICK DOOR WALK "
124 S$(25,1)=" FIRM PEND OATH SEEM PURE DENY MEAL DEBT WIRE MERE "
125 S$(26,1)=" BUCK TEXT BOLT FOLD COMA WELL NEAR PAIR CITY LOSS "
126 S$(27,1)=" HERE LIFT MORE BANK PLAY ROAD SOFT COUP SLIP LAME "
127 S$(28,1)=" SPOT TRIP TASK SOON WISE LESS WHOM BIRD FIND RATE "
128 S$(29,1)=" WARM CLIP FALL WIMP TUNE TEAM LIST POLL DATE TIRE "
129 S$(30,1)=" SEAT PAST HOLY FUND PORT WELD POSE FOOT ABLE RISE "
130 REM -----
131 REM LOOP USED TO GENERATE AT STRING (V$) OF 10
132 REM WORDS RANDOMLY SELECTED FROM THE SERIES OF
133 REM STRINGS SHOWN ABOVE.
134 REM -----
135 V$=""
140 FOR C=1 TO 150
150     E=RND(30)
160     RP=RND(10)
170     P=((RP-1)*5)+1
180     EX((C)=MID$(S$(E,1),P,5)
185     V$=V$+EX$(C)
190 NEXT C

```

```

200   VS=VS+" "
210   LPRINT VS
220   L=LEN(VS):PRINT@0,"TEXT";E:FOR I=1 TO 400:NEXT I
225   PRINT@0,"":INPUT "SPEED";K
230   PRINT@T-B-64,"":PRINT@T-58,"":PRINT@T-
235   B+64,"":PRINT@T+70,""
236   REM -----
237   REM LOOP USED TO PRESENT THE GET READY ....
238   REM PROMPT.
239   REM -----
240   FOR I=1 TO B
250       FOR J=1 TO 150
260       NEXT J
270       PRINT@T-2*I+B,MID$(Z$,I,I)
300   NEXT I
310   FOR I=2 TO 16
320       FOR J = 1 TO 150
330       NEXT J
340       PRINT@T-B,MID$(Z$,I,B);
350   NEXT I
351   REM -----
352   REM LOOP USED TO PRESENT TEXT ON THE SCREEN. THE
353   REM STRING IS SCANNED ACROSS THE EIGHT CHARACTER
354   REM WIDE WINDOW AT A CONSTANT RATE. THE RATE IS
355   REM DETERMINED BY THE EXPERIMENTER AND ENTERED AT
356   REM THE START OF THE PROGRAM. AFTER ALL TEN WORDS
357   REM HAVE PRESENTED A NEW STRING CAN BE GENERATED
358   REM AND PRESENTED TO THE SUBJECT.
359   REM -----
370   FOR I=1 TO B
390       FOR J=1 TO K
400       NEXT J
410       PRINT@T-2*I+B,MID$(V$,I,I)
420   NEXT I
420   FOR I = 2 TO L
430       FOR J = 1 TO K
440       NEXT J
450       PRINT@T-B,MID$(V$,I,B)
460   NEXT I
470   GOTO 135

```

```

1  REM -----
2  REM PROGRAM TITLE: ECCSER/V1.
3  REM THIS PROGRAM PRESENTS TEN RANDOMLY SELECTED
4  REM WORDS IN ONE LOCATION ON THE SCREEN. THE RATE
5  REM OF TEXT PRESENTATION IS ENTERED BY THE EXPERI-
6  REM METER. THIS PROGRAM WAS USED IN STUDYING HOW
7  REM READING VARIED WITH ECCENTRICITY.
8  REM
7  REM -----
10  CLEAR 5000
40  B=8:T=480:Z$=" GET READY ....":K=150
50  DIM S$(100,2),V$(150)
60  PRINT CHR$(23)
70  OUT0,255
80  CLS
81  REM -----
82  REM SET OF TEXT USED TO GENERATE THE STRINGS
83  REM PRESENTED TO THE SUBJECTS.
84  REM -----
100 S$(1,1)=" HARM SLID NICK ZEAL REEF KNIT PUSH MYTH WAIT LION "
101 S$(2,1)=" YOUR WARN FIVE MOOD EDGE ROSE STEM HELM HELD VASE "
102 S$(3,1)=" FLAG VERY VEST JUST EACH GOLF SOFT HOME SEEM VIEW "
103 S$(4,1)=" SOME EVER VOTE BACK HARD UNDO LIKE IDEA UPON SAME "
104 S$(5,1)=" EASY PART WORK ALSO WENT THEM PEAT JUNK SICK MINK "
105 S$(6,1)=" OVER YEAR LOOK SHOT HINT AWAY OVEN ROLE REAL SHIP "
106 S$(7,1)=" MOST LEAD HOUR GOAL TEST CAMP NEST DAWN TIME BOTH "
107 S$(8,1)=" WITH WIPE TOLD EASE YARD RISK GOOD LAST REST LEFT "
108 S$(9,1)=" RICH CALL EVEN PLAN GIVE ONCE SIGN SENT ONLY OPEN "
109 S$(10,1)=" CODE RUST POST ELSE BEAR LINK SAID RIPE NEED PLEA "
110 S$(11,1)=" PARK NEWS THEN LOCK FACT DOWN WHEN BASE BEST TORN "
111 S$(12,1)=" MANY COME DARK PLUG FOUL HOLE HELP INTO SELL BEEN "
112 S$(13,1)=" TERM STOP SEND BILL TRUE KIND CASE DOES GOES RACE "
113 S$(14,1)=" REAP LAID PURE TALK DRUG STAR HAVE RUSH THAT MUCH "
114 S$(15,1)=" KILL GIFT MASS TREE THEY BONE DEAL DIRE BOUT THIS "
115 S$(16,1)=" MOVE GAIN WERE LOAD HUNT MIND GANG BOMB TEST FULL "
116 S$(17,1)=" FORM WORD GAME TOOL HAND GAVE JAIL NOTE IRON BOOK "
117 S$(18,1)=" TENT FROM JOIN CARE RANK BUMP CAME FEEL KNOW GRAB "
118 S$(19,1)=" MAKE TELL VARY FELT DONE LORD HIGH LONG SHOW ARMY "
119 S$(20,1)=" SUCH BELL VICE PAST AIDE KEPT NONE KEEP LOVE POUR "
120 S$(21,1)=" GRIP COST GRIN PUNT MAIL SALE FILL PLUS MISS BLOW "
121 S$(22,1)=" ARMS FREE KING COAT LIVE MEET BELT CASH GURU MADE "
122 S$(23,1)=" KNEW NAIL SOAP NAVY EXIT AREA MEAN FIRE MORE BALD "
123 S$(24,1)=" TAKE CULT POOR CORE SURE SLIM FEAR TICK DOOR WALK "
124 S$(25,1)=" FIRM PEND OATH SEEM PURE DENY MEAL DEBT WIRE MERE "
125 S$(26,1)=" BUCK TEXT BOLT FOLD COMA WELL NEAR PAIR CITY LOSS "
126 S$(27,1)=" HERE LIFT MORE BANK PLAY ROAD SOFT COUP SLIP LAME "
127 S$(28,1)=" SPOT TRIP TASK SOON WISE LESS WHOM BIRD FIND RATE "
128 S$(29,1)=" WARM CLIP FALL WIMP TUNE TEAM LIST POLL DATE TIRE "
129 S$(30,1)=" SEAT PAST HOLY FUND PORT WELD POSE FOOT ABLE RISE "
130 REM -----
131 REM LOOP USED TO GENERATE AT STRING (V$) OF 10
132 REM WORDS RANDOMLY SELECTED FROM THE SERIES OF
133 REM STRINGS SHOWN ABOVE.
134 REM -----
135 V$=""
140 FOR C=1 TO 10
150     E=RND(41)
160     RP=RND(10)
170     P=((RP-1)*5)+1
180     V$(C)=MID$(S$(E,1),P,5)
185     IF V$(C)<>=V$(C-1)

```



```

187         THEN GOTO189
188         ELSE GOTO150
189         VS=VS+EXS(C)
190     NEXT C
200     REM-----
201     REM SUBJECTS CONTROL WHICH IS DIODE USED AS FIXATION
202     REM STIMULI BY ENTERING A NUMBER (0,5,10,15,20)
203     REM WHICH REPRESENTS THE ECCENTRICITY WHICH WILL BE
204     REM TESTED.
205     REM -----
210     PRINT@0,"":
205     INPUT"0,5,10,15 OR 20";U
206     IFU=5THENOUT0,254
207     IFU=25THENOUT0,224
208     IFU=10THENOUT0,253
209     IFU=15THENOUT0,247
210     IFU=20THENOUT0,251
211     IFU=0THENOUT0,238
220     FOR I=1 TO 400:NEXT I
225     PRINT@0,"":INPUT "SPEED";K
230     PRINT@T-B-64,"":PRINT@T-58,"":PRINT@T-
235     B+64,"":PRINT@T+70,"":
236     LPRINT"ECCENTRICITY   K VALUE":LPRINT U,K
237     FOR I=1TO10 STEP5
238         LPRINT VS(I),VS(I+1),VS(I+2),VS(I+3),VS(I+4)
239     NEXT I
240     REM -----
250     REM LOOP USED TO PRESENT THE GET READY ....
260     REM PROMPT.
270     REM -----
280     FOR I=1 TO B
290         FOR J=1 TO 150
300             NEXT J
310             PRINT@T-2*I+B,MIDS(ZS,1,I)
320         NEXT I
330     FOR I=2 TO 16
340         FOR J = 1TO 150
350             NEXT J
360             PRINT@T-B,MIDS(ZS,I,B)
370     NEXT I
381     REM -----
390     REM LOOP USED TO PRESENT TEXT ON THE SCREEN.
400     REM AFTER ALL TEN WORDS HAVE PRESENTED A NEW STRING
410     REM CAN BE GENERATED AND PRESENTED TO THE SUBJECT.
420     REM -----
450     FOR I=1 TO 10
460         PRINT@474,VS(I)
470         FOR J=1 TO K
480             NEXT J
490             PRINT@474,B$
500                 FOR W = 2 TO INT(K/5)
510                     FOR J = 1 TO K
520                         NEXT W
530     NEXT I
540     GOTO 135

```

```

1  REM -----
2  REM PROGRAM TITLE: METHOD OF ADJUSTMENT/VERSION 4
3  REM THIS PROGRAM PRESENTS TEXT SERIALY IN THE
4  REM CENTER OF A WINDOW. THE SUBJECT CAN VARY THE
5  REM RATE OF THE TEXT BY USING A JOYSTICK INTERFACED
6  REM WITH THE COMPUTER. THIS PROGRAM WAS USED IN
7  REM THE EXPERIMENT COMPARING ROD AND CONE READING
8  REM PERFORMANCE.
9  REM -----
10 CLEAR 5000
20 DEFINT B,T,K,N
30 SUS="":DA="":BS="":VS=""
40 B=8:T=480:Z$=" GET READY ...."
50 DIM SS(100,2),VS(150)
60 OUT0,255
70 PRINT@0,"ENTER K VALUE":INPUT K
80 CLS
81 REM -----
82 REM SET OF TEXT USED TO GENERATE THE STRINGS
83 REM PRESENTED TO THE SUBJECTS.
84 REM -----
100 SS(1,1)=" HARM SLID NICK ZEAL REEF KNIT PUSH MYTH WAIT LION "
101 SS(2,1)=" YOUR WARN FIVE MOOD EDGE ROSE STEM HELM HELD VASE "
102 SS(3,1)=" FLAG VERY VEST JUST EACH GOLF SOFT HOME SEEM VIEW "
103 SS(4,1)=" SOME EVER VOTE BACK HARD UNDO LIKE IDEA UPON SAME "
104 SS(5,1)=" EASY PART WORK ALSO WENT THEM PEAT JUNK SICK MINK "
105 SS(6,1)=" OVER YEAR LOOK SHOT HINT AWAY OVEN ROLE REAL SHIP "
106 SS(7,1)=" MOST LEAD HOUR GOAL TEST CAMP NEST DAWN TIME BOTH "
107 SS(8,1)=" WITH WIPE TOLD EASE YARD RISK GOOD LAST REST LEFT "
108 SS(9,1)=" RICH CALL EVEN PLAN GIVE ONCE SIGN SENT ONLY OPEN "
109 SS(10,1)=" CODE RUST POST ELSE BEAR LINK SAID RIPE NEED PLEA "
110 SS(11,1)=" PARK NEWS THEN LOCK FACT DOWN WHEN BASE BEST TORN "
111 SS(12,1)=" MANY COME DARK PLUG FOUL HOLE HELP INTO SELL BEEN "
112 SS(13,1)=" TERM STOP SEND BILL TRUE KIND CASE DOES GOES RACE "
113 SS(14,1)=" REAP LAID PURE TALK DRUG STAR HAVE RUSH THAT MUCH "
114 SS(15,1)=" KILL GIFT MASS TREE THEY BONE DEAL DIRE BOUT THIS "
115 SS(16,1)=" MOVE GAIN WERE LOAD HUNT MIND GANG BOMB TEST FULL "
116 SS(17,1)=" FORM WORD GAME TOOL HAND GAVE JAIL NOTE IRON BOOK "
117 SS(18,1)=" TENT FROM JOIN CARE RANK BUMP CAME FEEL KNOW GRAB "
118 SS(19,1)=" MAKE TELL VARY FELT DONE LORD HIGH LONG SHOW ARMY "
119 SS(20,1)=" SUCH BELL VICE PAST AIDE KEPT NONE KEEP LOVE POUR "
120 SS(21,1)=" GRIP COST GRIN PUNT MAIL SALE FILL PLUS MISS BLOW "
121 SS(22,1)=" ARMS FREE KING COAT LIVE MEET BELT CASH GURU MADE "
122 SS(23,1)=" KNEW NAIL SOAP NAVY EXIT AREA MEAN FIRE MORE BALD "
123 SS(24,1)=" TAKE CULT POOR CORE SURE SLIM FEAR TICK DOOR WALK "
124 SS(25,1)=" FIRM PEND OATH SEEM PURE DENY MEAL DEBT WIRE MERE "
125 SS(26,1)=" BUCK TEXT BOLT FOLD COMA WELL NEAR PAIR CITY LOSS "
126 SS(27,1)=" HERE LIFT MORE BANK PLAY ROAD SOFT COUP SLIP LAME "
127 SS(28,1)=" SPOT TRIP TASK SOON WISE LESS WHOM BIRD FIND RATE "
128 SS(29,1)=" WARM CLIP FALL WIMP TUNE TEAM LIST POLL DATE TIRE "
129 SS(30,1)=" SEAT PAST HOLY FUND PORT WELD POSE FOOT ABLE RISE "
130 REM -----
131 REM LOOP USED TO GENERATE AT STRING (VS$) OF 150
132 REM WORDS RANDOMLY SELECTED FROM THE SERIES OF
133 REM STRINGS SHOWN ABOVE.
134 REM -----
140 FOR C=1 TO 150
150     E=RND(30)
160     RP=RND(10)
170     P=((RP-1)*5)+1
180     VS((C)=MIDS$(SS(E,1),P,5)

```

```

190     NEXT C
200     Q=1:G=1
210     FOR I=1 TO 400
220     NEXT I
230     PRINT@T-B-64,"":PRINT@T-58,"":PRINT@T-
235     B+64,"":PRINT@T+70,""
236     REM -----
237     REM LOOP USED TO PRESENT THE GET READY ....
238     REM PROMPT.
239     REM -----
240     FOR I=1 TO 3
250         FOR J=1 TO 150
260         NEXT J
270         P=((G-1)*5)+1
280         PRINT@474,MID$(Z$,P,5
290         G=G+1
300     NEXT I
310     FOR J=1 TO 100
320     NEXT J
330     PRINT@474," ";
340     FOR J=1 TO 100
350     NEXT J
351     REM -----
352     REM LOOP USED TO PRESENT TEXT ON THE SCREEN. THE
353     REM WORDS IN THE STRING ARE PRESENTED SERIALY AT A
354     REM RATE DEPENDENT ON THE VALUE OF K USED IN A
355     REM DELAY LOOP. BETWEEN EACH WORD A BLANK SPACE
356     REM (B$) IS PRESENTED ON THE SCREEN FOR 1/5 THE
357     REM TIME THE WORD IS PRESENTED. INPUT TO SLOW
358     REM THE TEXT OR SPEED IT UP IS TAKEN FROM THE
359     REM JOYSTICK THROUGH THE VARIABLE A. TEXT IS
360     REM SLOWED BY ADDING TO THE VALUE OF K OR
361     REM SUBTRACTING FROM IT.
362     REM -----
363     G=1
370     FOR I=1 TO 100
380         PRINT@474,(V$(I))
390         FOR J=1 TO K
400         NEXT J
410         PRINT@474,B$
420         FOR T=1 TO INT(K/5)
430         NEXT T
440         A=255-INP(0)
450         IF A=1 AND K>3 THEN K=K-3
460         IF A=2 THEN K=K+3
470         IF (I/10-INT(I/10))=0 AND A=3 THEN GOTO 10000
480     NEXT I
490     GOTO 135
500     OUT0,255
10000 LPRINT K
10010 GOTO 1

```

```

1  REM -----
2  REM PROGRAM TITLE: ACCEL/V1 THIS METHOD OF TEXT PRESENTATION
3  REM WAS ONE OF THE METHODS THAT WAS COMPARED IN
4  REM THE ANCILLARY EXPERIMENTS DESCRIBED IN THE APPENDIX.
5  REM TEXT IS PRESENTED SERIALY IN THE WINDOW AND THE RATE
6  REM OF TEXT PRESENTATION INCREASES FROM LOW TO HIGH RATES.
7  REM -----
10 CLEAR 5000:DEFINT B,T,K,N
40 B=8:T=480:Z$=" GET READY ....":SU$="":DA$="":K=150
50 DIM SS(100,2)
60 PRINT CHR$(23)
80 CLS
81 REM -----
82 REM SET OF TEXT USED TO GENERATE THE STRINGS OF 50
83 REM WORDS WHICH WERE PRESENTED TO THE SUBJECTS.
84 REM -----
100 SS(1,1)=" HARM SLID NICK ZEAL REEF KNIT PUSH MYTH WAIT LION "
101 SS(2,1)=" YOUR WARN FIVE MOOD EDGE ROSE STEM HELM HELD VASE "
102 SS(3,1)=" FLAG VERY VEST JUST EACH GOLF SOFT HOME SEEM VIEW "
103 SS(4,1)=" SOME EVER VOTE BACK HARD UNDO LIKE IDEA UPON SAME "
104 SS(5,1)=" EASY PART WORK ALSO WENT THEM PEAT JUNK SICK MINK "
105 SS(6,1)=" OVER YEAR LOOK SHOT HINT AWAY OVEN ROLE REAL SHIP "
106 SS(7,1)=" MOST LEAD HOUR GOAL TEST CAMP NEST DAWN TIME BOTH "
107 SS(8,1)=" WITH WIPE TOLD EASE YARD RISK GOOD LAST REST LEFT "
108 SS(9,1)=" RICH CALL EVEN PLAN GIVE ONCE SIGN SENT ONLY OPEN "
109 SS(10,1)=" CODE RUST POST ELSE BEAR LINK SAID RIPE NEED PLEA "
110 SS(11,1)=" PARK NEWS THEN LOCK FACT DOWN WHEN BASE BEST TORN "
111 SS(12,1)=" MANY COME DARK PLUG FOUL HOLE HELP INTO SELL BEEN "
112 SS(13,1)=" TERM STOP SEND BILL TRUE KIND CASE DOES GOES RACE "
113 SS(14,1)=" REAP LAID PURE TALK DRUG STAR HAVE RUSH THAT MUCH "
114 SS(15,1)=" KILL GIFT MASS TREE THEY BONE DEAL DIRE BOUT THIS "
115 SS(16,1)=" MOVE GAIN WERE LOAD HUNT MIND GANG BOMB TEST FULL "
116 SS(17,1)=" FORM WORD GAME TOOL HAND GAVE JAIL NOTE IRON BOOK "
117 SS(18,1)=" TENT FROM JOIN CARE RANK BUMP CAME FEEL KNOW GRAB "
118 SS(19,1)=" MAKE TELL VARY FELT DONE LORD HIGH LONG SHOW ARMY "
119 SS(20,1)=" SUCH BELL VICE PAST AIDE KEPT NONE KEEP LOVE POUR "
120 SS(21,1)=" GRIP COST GRIN PUNT MAIL SALE FILL PLUS MISS BLOW "
121 SS(22,1)=" ARMS FREE KING COAT LIVE MEET BELT CASH GURU MADE "
122 SS(23,1)=" KNEW NAIL SOAP NAVY EXIT AREA MEAN FIRE MORE BALD "
123 SS(24,1)=" TAKE CULT POOR CORE SURE SLIM FEAR TICK DOOR WALK "
124 SS(25,1)=" FIRM PEND OATH SEEM PURE DENY MEAL DEBT WIRE MERE "
125 SS(26,1)=" BUCK TEXT BOLT FOLD COMA WELL NEAR PAIR CITY LOSS "
126 SS(27,1)=" HERE LIFT MORE BANK PLAY ROAD SOFT COUP SLIP LAME "
127 SS(28,1)=" SPOT TRIP TASK SOON WISE LESS WHOM BIRD FIND RATE "
128 SS(29,1)=" WARM CLIP FALL WIMP TUNE TEAM LIST POLL DATE TIRE "
129 SS(30,1)=" SEAT PAST HOLY FUND PORT WELD POSE FOOT ABLE RISE "
130 REM -----
131 REM LOOP USED TO GENERATE AT STRING (VS$) OF 50
132 REM WORDS RANDOMLY SELECTED FROM THE SERIES OF
133 REM STRINGS SHOWN ABOVE.
134 REM -----
135 VS$=""
140 FOR C=1 TO 50
150     E=RND(30)
160     RP=RND(10)
170     P=((RP-1)*5)+1
180     EX((C))=MID$(SS(E,1),P,5)
185     VS$=VS$+EX$(C)
190 NEXT C
200 VS$=VS$+" "

```

```

210 LPRINT VS
220 L=LEN(V$):
230 Q=1:G=1
225 PRINT@0,"TEXT";E
230     FOR I=1 TO 400
240     NEXT I
250 PRINT@T-B-64,"":PRINT@T-58,"":PRINT@T-B+64,"":PRINT@T+70,""
260 REM -----
270 REM THIS LOOP PRESENTS THE "GET READY...." MESSAGE
280 REM IN THE WINDOW TO PREPARE SUBJECTS FOR THE TEXT.
290 REM -----
300 FOR I=1 TO 3
310     FOR J=1 TO 150
320     NEXT J
330     P=((G-1)*5)+1
340     PRINT@474,MID$(Z$,P,5)
350     G=G+1
360 NEXT I
370 FOR I=1 TO 100
375 NEXT I
380 PRINT@474," "
385 FOR J=1 TO 100
390 NEXT J
391 REM -----
392 REM THERE ARE 50 WORDS IN THE STRING GENERATED EARLIER.
393 REM EACH WORD IS DESIGNATED WITH A NUMBER (G) STARTING
394 REM WITH ONE. THE VALUE OF G INCREMENTS BY ONE SO THAT
395 REM EACH WORD IN THE STRING IS PRESENTED SEQUENTIALLY.
396 REM K IS THE VALUE OF A DELAY LOOP WHICH DECREASES
397 REM SO THAT THE TEXT CAN BE PRESENTED MORE QUICKLY.
398 REM -----
405 G=1
410 FOR I = 1 TO 4
420     FOR J=1 TO K
430     NEXT J
435     P=((G-1)*5)+1
436     PRINT@474,MID$(V$,P,5)
437     K=K-10
438 NEXT I
439 G=G+1
440 FOR I=5 TO B
450     FOR J=1 TO K
460     NEXT J
470     P=((G-1)*5)+1
480     PRINT@T-B,MID$(V$,P,5)
490 NEXT I
500 FOR I=9 TO 37
510     IF(I/5-INT(I/5))=0
520     THEN K=K-8.5
530     G=G+1
540     FOR J=1 TO K
550     NEXT J
560     P=((G-1)*5)+1
570     PRINT@T-B,MID$(V$,P,5)
580 NEXT I
590 FOR I=38 TO 67
600     IF(I/5-INT(I/5))=0
610     THEN K=K-3
620     G=G+1
630     FOR J=1 TO K
640     NEXT J

```

```

650             P=((G-1)*5)+1
660             PRINT@T-B,MID$(V$,P,5)
670     NEXT I
680     FOR I=68TOL
690         IF(I/5-INT(I/5))=0
700             THEN K=K-1
710             G=G+1
720             FOR J=1TOK
730                 NEXT J
740                 P=((G-1)*5)+1
750                 PRINT@T-B,MID$(V$,P,5)
760     NEXT I
770     PRINT$474,"  "
780     K=150
790     PRINT@0,REPEAT R OR DECEL D"
800     INPUTRES$
810     IF RES$="R"
820     THEN GOTO 135
830     IF RES$="D"
840     THAN RUN"DECEL/V1"

```

```

1  REM -----
2  REM PROGRAM TITLE: DECCEL/V1 THIS METHOD OF TEXT
3  REM WAS ONE OF THE METHODS THAT WAS COMPARED IN
4  REM THE ANCILLARY EXPERIMENTS DESCRIBED IN THE
5  REM APPENDIX. TEXT IS PRESENTED SERIALY IN THE
6  REM WINDOW. THE RATE OF TEXT PRESENTATION DECREASES
8  REM FROM HIGH TO LOW RATES.
9  REM -----
10 CLEAR 5000:DEFINT B,T,K,N
40 B=8:T=480:Z$=" GET READY ....":SU$="":DAS="":K=150
50 DIM SS(100,2)
60 PRINT CHR$(23)
80 CLS
81 REM -----
82 REM SET OF TEXT USED TO GENERATE THE STRINGS OF 50
83 REM WORDS WHICH ARE PRESENTED TO THE SUBJECTS.
84 REM -----
100 SS(1,1)=" HARM SLID NICK ZEAL REEF KNIT PUSH MYTH WAIT LION "
101 SS(2,1)=" YOUR WARN FIVE MOOD EDGE ROSE STEM HELM HELD VASE "
102 SS(3,1)=" FLAG VERY VEST JUST EACH GOLF SOFT HOME SEEM VIEW "
103 SS(4,1)=" SOME EVER VOTE BACK HARD UNDO LIKE IDEA UPON SAME "
104 SS(5,1)=" EASY PART WORK ALSO WENT THEM PEAT JUNK SICK MINK "
105 SS(6,1)=" OVER YEAR LOOK SHOT HINT AWAY OVEN ROLE REAL SHIP "
106 SS(7,1)=" MOST LEAD HOUR GOAL TEST CAMP NEST DAWN TIME BOTH "
107 SS(8,1)=" WITH WIPE TOLD EASE YARD RISK GOOD LAST REST LEFT "
108 SS(9,1)=" RICH CALL EVEN PLAN GIVE ONCE SIGN SENT ONLY OPEN "
109 SS(10,1)=" CODE RUST POST ELSE BEAR LINK SAID RIPE NEED PLEA "
110 SS(11,1)=" PARK NEWS THEN LOCK FACT DOWN WHEN BASE BEST TORN "
111 SS(12,1)=" MANY COME DARK PLUG FOUL HOLE HELP INTO SELL BEEN "
112 SS(13,1)=" TERM STOP SEND BILL TRUE KIND CASE DOES GOES RACE "
113 SS(14,1)=" REAP LAID PURE TALK DRUG STAR HAVE RUSH THAT MUCH "
114 SS(15,1)=" KILL GIFT MASS TREE THEY BONE DEAL DIRE BOUT THIS "
115 SS(16,1)=" MOVE GAIN WERE LOAD HUNT MIND GANG BOMB TEST FULL "
116 SS(17,1)=" FORM WORD GAME TOOL HAND GAVE JAIL NOTE IRON BOOK "
117 SS(18,1)=" TENT FROM JOIN CARE RANK BUMP CAME FEEL KNOW GRAB "
118 SS(19,1)=" MAKE TELL VARY FELT DONE LORD HIGH LONG SHOW ARMY "
119 SS(20,1)=" SUCH BELL VICE PAST AIDE KEPT NONE KEEP LOVE POUR "
120 SS(21,1)=" GRIP COST GRIN PUNT MAIL SALE FILL PLUS MISS BLOW "
121 SS(22,1)=" ARMS FREE KING COAT LIVE MEET BELT CASH GURU MADE "
122 SS(23,1)=" KNEW NAIL SOAP NAVY EXIT AREA MEAN FIRE MORE BALD "
123 SS(24,1)=" TAKE CULT POOR CORE SURE SLIM FEAR TICK DOOR WALK "
124 SS(25,1)=" FIRM PEND OATH SEEM PURE DENY MEAL DEBT WIRE MERE "
125 SS(26,1)=" BUCK TEXT BOLT FOLD COMA WELL NEAR PAIR CITY LOSS "
126 SS(27,1)=" HERE LIFT MORE BANK PLAY ROAD SOFT COUP SLIP LAME "
127 SS(28,1)=" SPOT TRIP TASK SOON WISE LESS WHOM BIRD FIND RATE "
128 SS(29,1)=" WARM CLIP FALL WIMP TUNE TEAM LIST POLL DATE TIRE "
129 SS(30,1)=" SEAT PAST HOLY FUND PORT WELD POSE FOOT ABLE RISE "
130 REM -----
131 REM LOOP USED TO GENERATE A STRING (V$$) OF 50
132 REM WORDS RANDOMLY SELECTED FROM THE SERIES OF
133 REM STRINGS SHOWN ABOVE.
134 REM -----
135 V$=""
140 FOR C=1 TO 50
150     E=RND(30)
160     RP=RND(10)
170     P=((RP-1)*5)+1
180     EX((C)=MID$(SS(E,1),P,5)
185     V$=V$+EX$(C)
190 NEXT C

```

```

200 V$=V$+" "
201 REM-----
202 REM THE FOLLOWING CODE PRINTS THE SUBJECTS NAME AND
203 REM TEST INFORMATION. A COPY OF THE TEXT PRESENTED
204 REM TO THE SUBJECT IS ALSO PRINTED OUT SO THAT IT
205 REM CAN BE COMPARED TO WHAT THE SUBJECT READS ALOUD.
206 REM-----
207 LPRINT "TEST: DECELERATION TEST"
208 LPRINT " "
209 LPRINT "SUBJECT NAME: ";LPRINTSUB$
210 LPRINT " ":LPRINT
211 LPRINT "DATE: ";LPRINT DAS
220 L=LEN(V$);
230 Q=1
240 FOR D=1TO246 STEP5
245     LPRINT Q,MID$(V$,D,5)
246     Q=Q+1
247 NEXT D
250 FOR H=1TO12
255     LPRINT" "
260 NEXT H
265 FOR I=1TO 400
270 NEXT I
270 PRINT@T-B-64,".:PRINT@T-58,".:PRINT@T-B+64,".:PRINT@T+70,":
280 REM -----
290 REM THIS LOOP PRESENTS THE "GET READY...." MESSAGE
300 REM IN THE WINDOW TO PREPARE SUBJECTS FOR THE TEXT.
310 REM -----
320 FOR I=1 TO B
330     FOR J=1 TO 150
340     NEXT J
350     P=((G-1)*5)+1
360     PRINT@T-2*I+B,MID$(Z$,I,I)
370 NEXT I
380 FOR I=2TO16
390     FOR J=1 TO 150
400     NEXT J
410     PRINT@T-B,MID$(Z$,I,B)
415 NEXT I
440 REM -----
450 REM THERE ARE 50 WORDS IN THE STRING GENERATED EARLIER.
460 REM EACH WORD IS DESIGNATED WITH A NUMBER STARTING
470 REM AT ONE. THE VALUE OF G INCREMENTS BY ONE SO THAT
480 REM EACH WORD IN THE STRING IS PRESENTED SEQUENTIALLY.
490 REM K IS THE VALUE OF A DELAY LOOP WHICH INCREASES
500 REM SO THAT THE TEXT CAN BE PRESENTED MORE SLOWLY.
510 REM -----
530 FOR I = 1TOB
540     FOR J=1TOK
550     NEXT J
560     PRINT@T-2*I+B,MID$(V$,I,I)
590 NEXT I
610 FOR I=2TO30
615     IF(I/5-INT(I/5))=0
616     THEN K=K+.1
620     FOR J=1TOK
630     NEXT J
650     PRINT@T-B,MID$(V$,I,B)
660 NEXT I
670 FOR I=31TO60
680     IF(I/5-INT(I/5))=0

```



```

690         THEN K=K+.75
710         FOR J=1TOK
720         NEXT J
740         PRINT@T-B,MID$(V$,I,B)
750     NEXT I
760     FOR I=61TO110
770         IF(I/5-INT(I/5))=0
780         THEN K=K+1
800         FOR J=1TOK
810         NEXT J
830         PRINT@T-B,MID$(V$,I,B)
840     NEXT I
850     FOR I=110TOL
860         IF(I/5-INT(I/5))=0
870         THEN K=K+1.5
890         FOR J=1TOK
900         NEXT J
920         PRINT@T-B,MID$(V$,I,B)
930     NEXT I
935     K=1
950     PRINT@0,REPEAT R OR DECEL D"
960     INPUTRES$
970     IF RES$="R"
980     THEN GOTO 135
985     IF RES$="D"
990     THAN RUN"DECEL/V1"

```

Pascal program used to present words serially in window. The following program was used to simulate the reading task on a Mac II computer so that the stability of the subjects eye fixations could be monitored while they read. The subjects eye fixations were monitored using a corneal flection system. This program was written by Aspi Jimmy Havewala.

```

Program fix;
{ *--
*--Program written by Aspi Jimmy Havewala
*--May 9, 1990
*--Program to display 10 letter string each letter of 4 characters on screen. The time for which each word is displayed
and time for which blank between each word is displayed is controlled. The program uses two data files: exp.dat--
contains data which controls parameters of the experiment, cfix.dat file contains list of words to be displayed.
*--}

```

```

USES    Memtypes, Quickdraw, OSintf, Toolintf;

```

```

CONST
    words      = 300;    {no of words in data file dfix.dat}
    len        = 4;      {length of each word}
    lettersize  = 256;    {size of characters displayed}
    TSIZE      = 150     {size of text}
    BSIZE      = 50;     {size of blocks on window}

```

```

TYPE
    str1      = array[1..words] of string[len];    {array type for holding strings}

```

```

VAR
    windRect : Rect;    {size of window}
    letters,  : integer; {color of letters to be displayed}
    myfile,   : string;  {file for list of words}
    expfile   : text;    {and experiment data}
    mystr     : str1;    {holds word list in memory}
    i,
    atimes    : integer; {parameters read from file}
    d1,d2,d3  : real;
    wnum      : integer;
    dummy     : string[80]; {dummy to read off comments in file}
    myColor   : RGBcolor;

```

```

Procedure initialize;
{this procedure initializes everything we need and opens an appropriate window}

```

```

VAR
    myport    :windowPtr;
    error     :OSErr;
    theWorld  :SysEnvRec;

```

```

BEGIN
    {open the files for reading}
    open (myfile,'cfix.dat');
    open (expfile,'exp.dat');

    {initialize all the needed managers.}
    initGraf(@the Port);
    initFonts;
    InitWindow;
    initMenus;
    Telnit;
    initDialogs(NIL);
    initCursor;

```

```

        New (myport);
        OpenPort (myport);

        windRect :=screenBits.bounds;

        {myport :=NewCWindows (NIL,windRect,' ', TRUE,plainDBox,Pointer(-1),False,0);
        setport (myport);}
END; {initialize}

procedure blankmes;

VAR
    box      :rect;

begin
    setrect (box,200,150,600,300);
    ForeColor (blackcolor);
    PaintRect (box);
    ForeColor (bluecolor);
end;

procedure pushbutton;
{procedure for waiting for user to press mouse to begin}

begin
    repeat
    until Button;
end;

procedure makerefwindow;
{makes a reference window consisting of four dots within which the words will be displayed}

VAR
    box      :rect;

begin
    Textsize (BSIZE);
    moveto (120,300);
    drawstring ('.');
    moveto (120,480);
    drawstring ('.');
    moveto (620,300);
    drawstring ('.');
    moveto (620,480);
    drawstring ('.');
end;

procedure black;
{procedure to blank out words on screen}

VAR
    box      :rect;

begin
    setrect (box,130,300,610,470);
    ForeColor (blankcolor);
    PaintRect (box);
    ForeColor (bluecolor);
    {RGBForeColor (mycolor);}
end;

```

```

procedure mydelay (seconds :real);
{procedure to cause a delay of x seconds. uses the system cloc. maximum accuracy is 1/67th of a second}

```

```

VAR

```

```

    tickvalue :longint;
    temp      :integer;

```

```

begin

```

```

    tickValue := Tickcount;
    temp := round(67*seconds);
    tickvalue := tickvalue + temp;
    repeat
    until (Tickcount >= tickValue);

```

```

end;

```

```

procedure dostring (list :str1:d1,d2 :real);

```

```

{list of array of 10 strings each up to 10 characters. d1 is time for which each string is to be displayed on the screen in
seconds. d2 is time for which blank between strings is to be displayed in seconds = 1/5 * d1}

```

```

VAR

```

```

    j      : integer;

```

```

begin

```

```

    TextSize (TSIZE);
    for j := 1 to 10 do
        begin
            moveTo (130,470);
            if wnum > words then
                wnum := 1
            else
                wnum := wnum + 1;

            DrawString (list [wnum]);
            mydelay(d1);
            blank;
            mydelay (d2);
        end;

```

```

end;

```

```

begin

```

```

    initialize;

```

```

    myColor.red      :=0;
    myColor.Green    :=20000;
    myColor.Blue     :=0;

```

```

    for i := 1 to words do
        begin
            readln (myfile, mystr[i]);
        end;

```

```

    hidecursor;
    {set all text attributes}
    TextFont (10);
    TextFace ({bold});
    TextMode (srcor);

```

```

    {set background color to black with backgrnd do begin
        red :=0; blue :=0; green :=0;
    end;}

```

```

{set letters to desired luminance with letters do begin
    red :=65535; blue :=65535; green :=65535;
end;}

ForeColor (blackcolor);
paintrect (windirect;
ForeColor (bluecolor);    {luminance of text}
{RGBForeColor (mycolor);  luminance of text}

makerefwindow;
TextSize (lettersize);

{read our dummy comment lines}
for i:= 1 to 5 do
    readlin (expfile,dummy);

wnum :=1;
repeat
    readlin (expfile,d1,atimes);
    d2 :=1/5*d1;
    for i:=1 to atimes do
        dostring (mystr,d1,d2);
        ready;
    until EOF(expfile);
end.

```