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INDEPENDENCE OF FOVEAL RETINAL LOCUS AND VISUAL DETECTION PARADIGM

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Walter Schneider and Arthur D. Fisk

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20 memory set size 2, number of display channels 2, memory set either consistently or variably mapped, and frame time of 100 or 200 msec for the consistent or variably mapped conditions, respectively. The main effects of experimental paradigm and retinal locus were significant, but the interactions were not. The results are discussed in terms of an automatic letter encoding stage which could take the form of a discrete stage or a continuous output which cascades into the next stage for search and detection.

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Independence of Foveal Retinal Locus and
Visual Detection Paradigm

Walter Schneider and Arthur D. Fisk

Report 8001

Human Attention Research Laboratory

University of Illinois

February 9, 1980

Running Head: Retinal Locus/Visual Detection

Abstract

The effect of horizontal retinal locus at -3 , -2 , -1 , $-.5$, 0 , $.5$, 1 , 2 , 3 degrees visual angle was examined in a variety of reaction time and detection paradigms. Seven subjects participated in a two alternative 2:1 choice reaction time task, Posner match task, and a scanning memory set size 1 and 3 task. In a second experiment subjects participated in a consistent or varied mapping memory set size 2, display size 2 reaction time task. Also, a multiple frame detection paradigm task measured detection probability with memory set size 2, number of display channels 2, memory set either consistently or variably mapped, and frame time of 100 or 200 msec for the consistent or variably mapped conditions, respectively. The main effects of experimental paradigm and retinal locus were significant, but the interactions were not. The results are discussed in terms of an automatic letter encoding stage which could take the form of a discrete stage or a continuous output which cascades into the next stage for search and detection.

Retinal Locus/Visual Detection

Many recent visual information processing paradigms implicitly assume that retinal locus has a minor effect on central cognitive processing rate and does not interact with processing demands. Reaction times for simultaneously presented "same" and "different" name match increase nearly 100 msec from fovea to 4 degrees outward (Lefton & Haber, 1974; Fisher & Lefton, 1976). Vocal reaction time to four target letters increased approximately 50 msec from fovea to 3 degrees outward (Eriksen & Schultz, 1977). When degraded stimuli were used the increase was approximately 100 msec. Since spatial acuity reduces with visual angle (Riggs, 1965), the deterioration with visual angle is expected.

Discrete stage approaches to perception generally assume that the encoding stage does not interact with later stages. For example, Sternberg (1967) demonstrated that, after one session of practice, stimulus degradation and number of memory comparisons did not interact, suggesting the stages are independent. Wardzinski and Pachella (in press) replicated the Sternberg result and extended it to show that degrading the signal by reducing foreground background contrast and adding a noise mask did not interact with memory set size or whether search was for name identical or physically identical probes.

Recent visual detection experiments (Schneider & Shiffrin, 1977) have suggested that there are two qualitatively different types of search processes. When targets are consistently searched for, a fast effortless automatic processing occurs which is relatively uninfluenced by increases in memory load and number of channels. When a varied target set is used, in which target letters on one trial become distractors on others, a slow controlled processing occurs. Relative to the automatic processing, controlled processing is slow, effortful, and performance decreases with increases in memory load and number of channels.

The encoding of common letters at different retinal locations within the fovea would be predicted to be automatic. College undergraduates are well practiced at reading letters. Hence, no interaction between retinal locus and type of search task is expected. Note if novel characters are utilized there may be interactions during the period of letter coding acquisition (e.g., Laberge, 1973; Laberge & Samuels, 1974).

The present experiments examine the effects of retinal locus on a variety of experimental paradigms. Reaction time performance was measured in a two alternative 2:1 choice reaction time experiment, a Posner match experiment, and memory set size 1 and 3 scanning experiments. Automatic and controlled processing performance as a function of retinal locus was examined utilizing two paradigms, reaction time and multiple frame time limited detection. Assuming that automatic encoding proceeds the experimentally manipulated stage, retinal locus should not interact with these manipulations.

Experiment 1

Method

Subjects. Seven paid University of Illinois undergraduate and graduate students were used in this experiment. All had normal or corrected to normal vision.

Apparatus and Stimuli. These experiments were controlled by a Digital Equipment Corporation PDP 11/34 computer. Timing of displays and reaction times was accurate to the nearest millisecond. Stimuli were presented on a Tektronics 604 cathode ray tube with a P4 phosphor. Letters were high resolution characters drawn on a 32 wide by 48 high dot matrix, averaging 43 dots per character. Characters were .52 degrees wide by .58 degrees high, were generated from a letter gothic capital type font, and refresh rate was once every 10 milliseconds. Subjects sat 45 cm from the CRT screen, and used a chin rest. Responses were made by pushing over-travel microswitches (Microswitch BZ-2RS-A2) with their preferred hand. Subjects were run two at a time.

Procedure. The horizontal retinal locus varied between trials taking on the values of 0, + .5, + 1, + 2, and + 3 degrees from the center fixation point. There were an equal number of presentations on the left and right visual field, and the probability of a yes and a no response was equal. There were four experimental paradigms which varied between blocks. The first paradigm was a consistently mapped (CM) 2 alternative 2:1 choice reaction time task which was similar to the Eriksen and Schultz (1977) experiment. In this condition subjects had a consistent mapping of stimuli to responses. If an A E occurred they pushed one button, if an O U occurred they pushed a second button. For half the subjects the A E was the yes button, the other half O U. Each trial had the following sequence. A display of AE OU was presented 2.98 degrees above the center of the two fixation dots. After 30 seconds, or when both subjects pushed a ready button with their non-preferred hand, two vertically oriented fixation dots appeared in the center of the screen 1.19 degrees apart. Subjects were instructed to fixate in the center between the two dots. The fixation dots remained for 500 milliseconds, the screen went blank for 75 milliseconds, then a character was presented in one of the seven display locations for 50 milliseconds (5 display refreshes). The subjects were allowed up to 4 seconds to respond.

The second and third paradigms involved a Sternberg (1966) varied mapping memory scanning search with the memory set size of 1 or 3 letters. The letters could be any letters of the alphabet except A, E, O, U. In the varied mapping memory set size 1 condition (VM 1), subjects were presented one letter as a memory set at the beginning of each trial. The subject's task was to respond yes if the probe letter was a member of the memory set, else no. In the varied mapping memory set size 3 condition (VM 3), subjects were presented three letters as a memory set. A new memory set was selected on each trial. The memory set was presented above and to the left of the fixation dot as in the previous condition. In all other respects this condition was the same as the consistently mapped condition.

The fourth paradigm utilized a Posner (Posner & Taylor, 1969) same/different visual matching task, and was a replication of the Lefton and Haber (1974) experiments I and II. In this case the orientation frame presented an "SD" indicating the same/different task. Only one focus dot was presented in the center of the screen. The probe consisted of two letters presented in a vertical column having .6 degrees separation. Subjects pushed the yes button if the two letters were the same, the no button if they were different. Since only capital letters were used, subjects could perform this task either on a name or physical match basis. The stimulus letters could be any capital letter

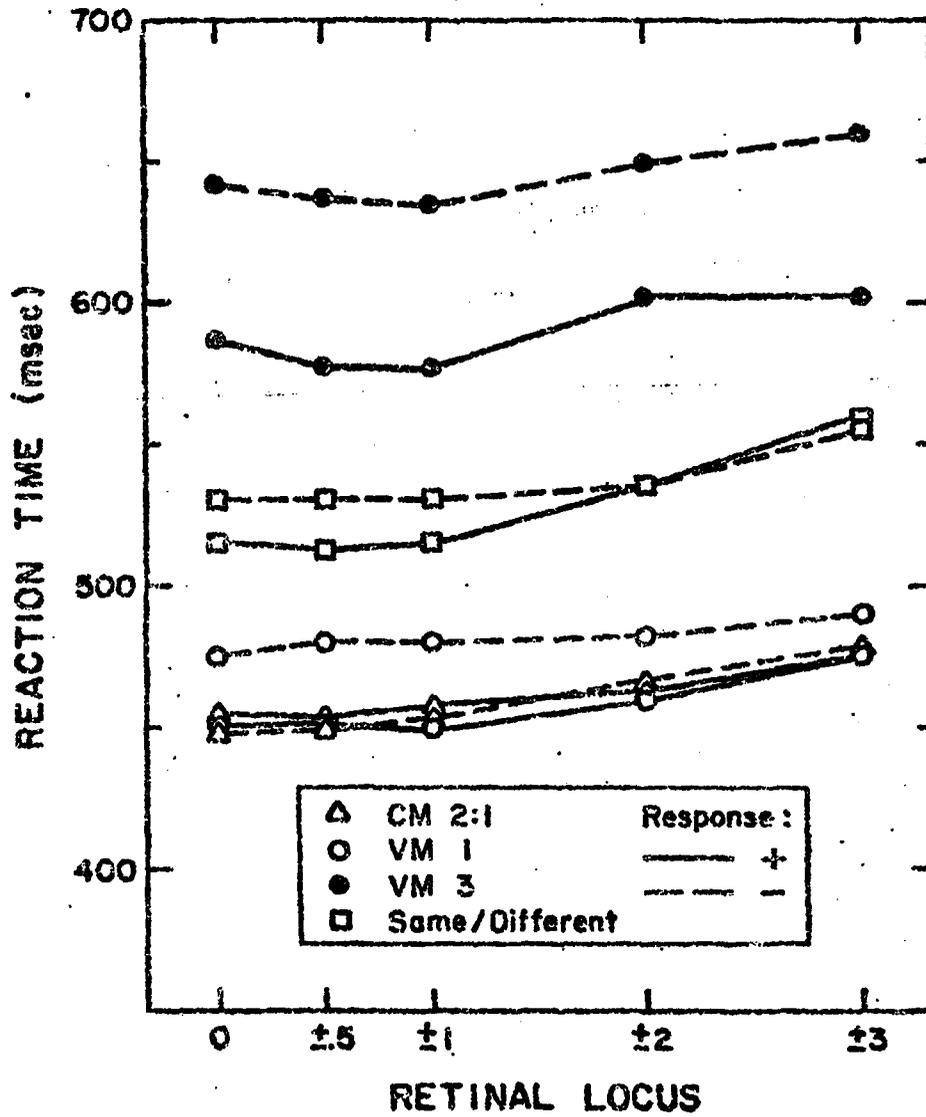


Figure 1. Experiment 1, effect of retinal locus on reaction time. Right and left visual fields combined.

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Table 1. Experiment 1

Averaged over subjects

Condition	Intercept	Slope	Slope excluding 0°	Correlation slope and retinal locus 0°-3°	Error probability
CM +	453	6.6	5.9	.943	.014
CM -	440	10.3	12.5	.995	.010
VMI +	450	7.5	8.9	.907	.022
VMI -	473	4.8	4.9	.954	.010
VMS +	579	7.6	11.1	.777	.036
VMS -	635	7.4	10.3	.857	.022
SD +	507	14.8	18.0	.956	.020
SD -	526	8.0	10.0	.940	.016

exclusive of A, E, O, U. In all other respects this paradigm was the same as above.

Subjects typically ran from 4 to 6 blocks per hour for a total of 9 hours. In all the experimental conditions, subjects were given error feedback consisting of both an error tone and a red LED error light which remained on until the subjects pushed the ready button for the next trial. Each block contained 10 practice trials and 180 data trials. There were a total of 56 conditions (7 retinal locations X 4 experimental paradigms X yes/no response). Dependent variables were reaction time and accuracy of the response to the probe, and study time of the orientation frame.

Results and Discussion

The first four hours were treated as practice and only the final six blocks per condition were analyzed. Figure 1 presents the results of the last six blocks of each condition. There were approximately 710 correct observations per point for the central fixation conditions, and 1410 observations for the other fixation conditions. Table 1 presents a summary of the results. The main effects of retinal locus from 0 to ± 3 degrees ($F(3,18)=53$ $p<.000001$) and experimental condition ($F(3,18)=50$ $p<.000001$) were significant. Left versus right fixation ($\pm .5$ to ± 3 degrees) ($p<.84$) and trial type (yes/no) ($p<.18$) were not. There was an experimental condition X trial type interaction ($F(3,18)=7.8$ $p<.002$). None of the other interactions reached statistical significance. A test for interaction between retinal locus from .5 to 3 degrees (dropping out the central fixation condition) X experimental condition was marginally significant ($F(9,54)=2.1$ $p=.044$). The simple main effect of retinal locus was significant in all conditions ($p<.01$). Table 1 presents the reaction time slope and intercepts, and error rates in each condition. The reaction time at zero degrees and at plus or minus .5 degrees was approximately equal. When the zero degree condition is excluded, the slope is slightly higher (see Table 1). Except for condition VM 3, the linear trend accounts for a large proportion of the variance (see Table 1). The slopes in general are small, ranging from 4.8 to 14.8 milliseconds per degree. Slope in the consistently mapped condition, which was a replication of the Eriksen and Schultz condition, was 7.8 milliseconds. This was less than the 19 milliseconds per degree in the Eriksen and Schultz experiment. This difference may be due to greater practice, manual as opposed to vocal response, or the use of a different display in this experiment versus the Eriksen and Schultz experiment.

The slope of the same/different task, which replicates Lefton and Haber, was 14.8 milliseconds which is approximately the same as the 16 milliseconds per degree (estimated from graph) seen in the Lefton and Haber study. The complex interaction between the same/different task and retinal location was not observed in the summed data in the present experiment. However, one subject did show the pattern of results reported by Lefton and Haber, in which the same match was faster for retinal locations 0, $\pm .5$, ± 1 degrees and slower at ± 2 and ± 3 degrees than the different condition (cf Lefton & Haber, 1974; Fisher & Lefton, 1976; Hellige, 1976). The lack of replication of the previously observed interaction between retinal locus and positive and negative response in the same/different paradigm may be the result of individual differences between subjects, different levels of practice, or greater spatial separation between

probe letters (e.g., this experiment used .6 degrees separation and Lefton and Haber used .15 degrees).

The varied mapping search conditions, VM 1 and VM 3, had a visual angle effect of 7.2 and 7.6 milliseconds per degree, respectively. The slope was not significantly different between these conditions. This result suggests that retinal locus affects coding time but does not interact with the number of comparisons. The effect of trial type (yes/no) was significant for VM 3 ($F(1,6)=23.6, p<.005$) but not for any other conditions.

The right versus left retinal field effect was not significant. This is consistent with the Lefton and Haber (1974), and Eriksen and Schultz (1977) results, though inconsistent with other retinal field results (see Hellige, 1976).

Examination of individual subject graphs showed relatively little of the variability in all conditions except VM 3. Since the VM 3 condition requires potentially three comparisons to memory, it places the greatest demand on controlled processing. The results suggest that individual differences played a greater role in control processing comparisons than automatic encodings.

The present results allow us to make three conclusions. First, manipulation of visual angle in the ranges zero to three degrees has relatively little effect on reaction time. Second, there appears to be no interaction between a variety of experimental reaction time tasks and visual angle, suggesting the processes affect different stages. Third, there is a greater range of individual differences in the multiple comparison control process task (VM 3), than in the other conditions.

The next experiment determined whether there was an effect of visual angle when multiple characters were present in the visual field. This experiment examines the ability of subjects to locate the target letter in a visual search, whereas the previous experiment required only identification of a single letter.

Experiment 2

Method

Subjects. Eight paid subjects were used in this experiment. Three of the subjects had participated in Experiment 1, all others were naive to the task. There was a one month delay between Experiments 1 and 2.

Apparatus and Stimuli. The apparatus and stimuli were the same as before, except now each probe display contained four character positions. Two character positions contained letters, and two contained random dot patterns. Each random dot pattern had 43 dots randomly positioned on the 32 by 48 dot grid. The positions of the two letters in each frame were randomly determined. The stimuli were presented in a square around a central fixation point. All retinal distances were from the central fixation dot to the center of the character. In all other respects the displays were the same as in Experiment 1.

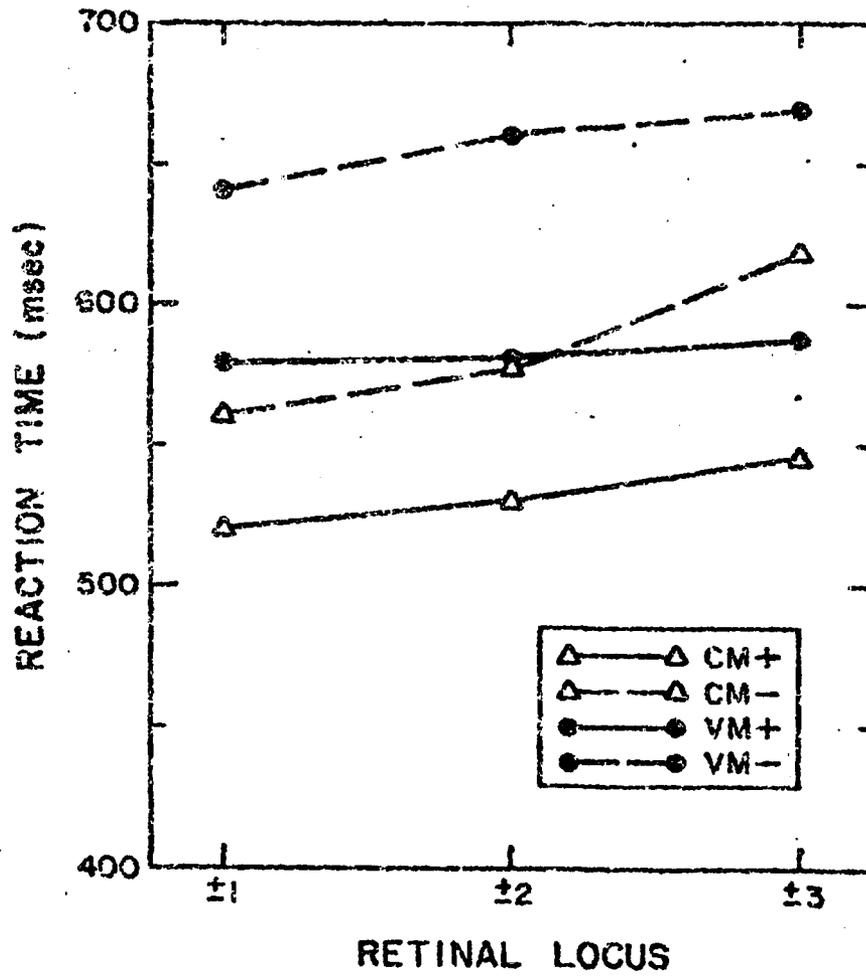


Figure 2. Experiment 2 single frame reaction times as a function of retinal locus.

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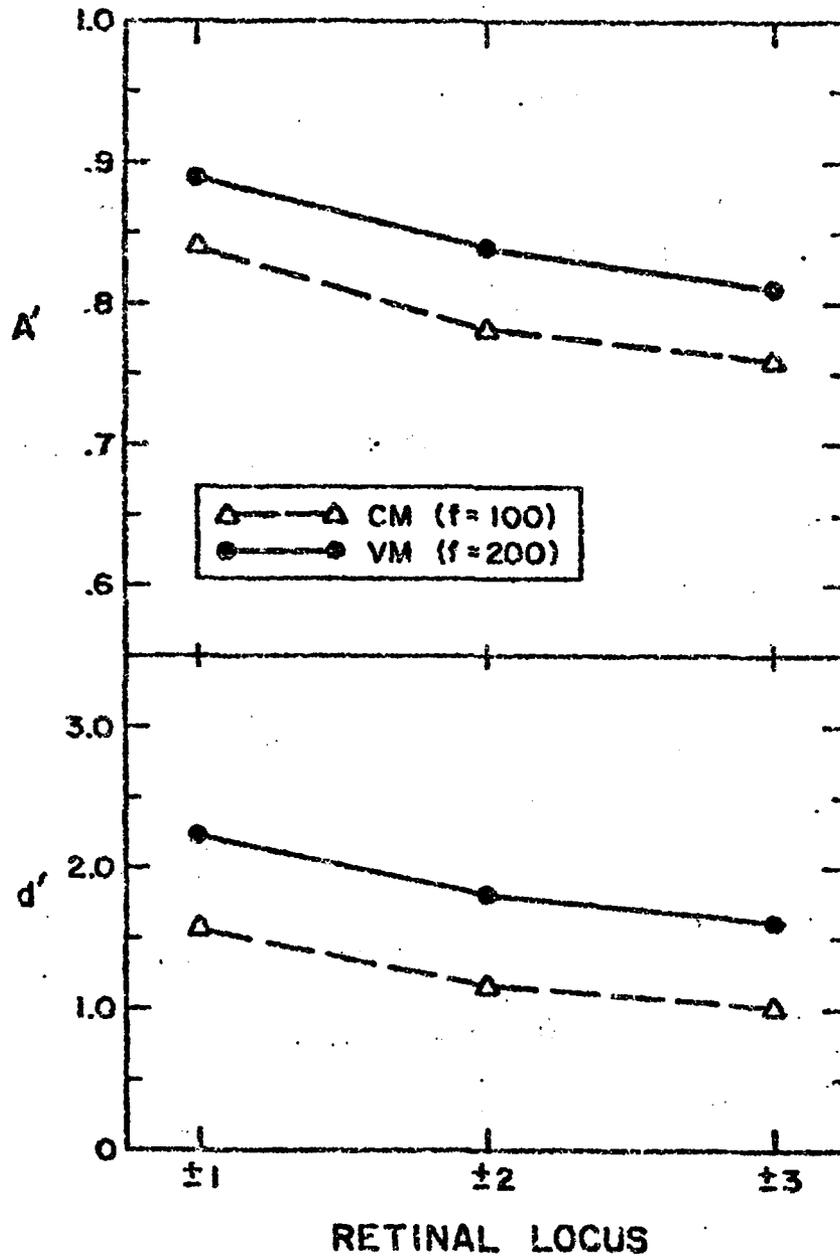


Figure 3. Experiment 2 multiple frame detection performance as a function of retinal locus.

Procedure. In this experiment there were three types of independent variables. These were types of mapping (consistent or varied) X type of search (single frame reaction time or multiple frame detection) X retinal locus (1, 2, or 3 degrees visual angle). The consistent and varied mapped search sets were disjoint sets of letters randomly chosen from A-Z. The memory set size was 2, the display size was also 2. Thus subjects would potentially have to make four comparisons to compare each memory set item to each display item. A single frame and multiple frame procedure was used. The single frame procedure was similar to the VM procedures of Experiment 1. The memory set was displayed for 30 seconds or until the subject pushed the initiation button, a focus dot was presented for .5 seconds, then the probe display of the characters was presented until the subject responded. The dependent variables were the proportion of hits and false alarms, and reaction time.

In the multiple frame procedure a series of 12 displays were presented. A trial sequence consisted of displaying the memory set for 30 seconds or until the subject pushed the initiation button, a focus dot for .5 seconds, then 12 displays each containing two characters and two random dot masks. Either 0 or 1 target letter would appear on one of the displays from display 3 through 11. All other displays contained only distractor letters. The display time, onset of one display until onset of the next, was 200 milliseconds in the varied mapping (VM) condition and 100 milliseconds in the consistent mapping (CM) condition. These frame times were selected so subjects would generate approximately equal memory set accuracy performance in the VM and CM conditions. Subjects were instructed to respond as soon as they saw a target, and if they saw no target to push the no button at the end of the sequence of displays. On errors, a tone and error light were presented.

The between trial conditions were stimulus present or absent, and visual angle of 1, 2, or 3 degrees. Subjects were not given an indication of what retinal locus condition the trial would be (although in the multiple frame condition the first frame was at the same retinal locus as all the rest). The conditions were permuted randomly within a block of 10 practice and 96 test trials. The consistent versus varied mapping, and single versus multiple frame conditions were manipulated between blocks. Subjects ran a total of 60 blocks.

Results and Discussion

The results for the last five blocks in each condition are presented in Figure 2 (single frame procedure) and Figure 3 (multiple frame procedure). In the single frame condition the main effects of processing mode (CM or VM) ($F(1,7)=38.8$ $p<.0001$), trial type (yes/no) ($F(1,7)=13.5$ $p<.001$), and retinal locus ($F(2,14)=25.2$ $p<.0001$) were significant. The processing mode X trial type interaction was significant ($F(1,7)=8.7$ $p<.02$). Processing mode X retinal location was marginally significant ($F(3,14)=3.44$ $p=.06$). All other interactions were nonsignificant. A statistical analysis of the slopes showed no significant effects of processing mode or trial type. The consistent mapping conditions showed a 11.5 millisecond per degree effect of visual locus on positive reaction time, and a 27 millisecond slope on negative reaction time, or a combined positive and negative effect of 19 milliseconds per degree. The varied mapping conditions showed the same pattern with a 5 millisecond per degree slope with the positive reaction times, 13 milliseconds per degree for

the negatives, and 9 milliseconds combined. The varied and consistently mapped condition retinal locus slopes were similar.

In the multiple frame procedure, the CM d' and A' (Norman, 1964; Pollack & Norman, 1964; Craig, 1979) were somewhat lower than, but not significantly different from, the VM performance. A' is a measure of sensitivity ranging from chance (.5) to perfect detection (1.0). It makes less distributional assumptions than d' and is more robust when false alarms become very rare as in the present data. Note that the displays in the CM condition were on for 100 milliseconds, and in the VM condition 200 milliseconds (had the VM condition been at 100 msec display, performance would have been far inferior to CM (see Schneider & Shiffrin, 1977, figure 3)). The effect of retinal locus of the arcsin transformed proportion correct data was significant ($F(2,14)=14$, $p<.0005$). The main effect of yes/no ($F(1,7)=30$, $p<.0001$) and the interaction between CM/VM and yes/no ($F(1,7)=26$, $p<.002$) were significant. These last two effects were due to a greater proportion of false alarms in the CM condition. The arcsin transformed A' analysis showed no CM/VM difference ($F(1,7)=3.66$, $p=.097$), and a significant retinal locus effect ($F(2,14)=18.7$, $p<.0002$). The interaction was not significant.

The results indicate that, after five hours of training, retinal locus in the range of 0 to 3 degrees has approximately 10 msec per degree effect on reaction time over a variety of letter comparison measures. In the multiple frame procedure, target detection sensitivity decreased approximately .45 d' units and .06 A' units from one to two degrees and approximately .15 d' and .03 A' units from two to three degrees. Retinal locus did not interact with the number of comparisons or the mode of processing (automatic or controlled). The interpretation of this lack of interaction is somewhat problematic. The choice of frame time succeeded in producing a non-significant effect of processing mode. It is possible that the effect of frame time interacts with retinal locus in a way which will exactly cancel the interaction between processing mode and retinal locus. This, however, seems unlikely in displays where letters can be clearly identified. It is quite likely that frame time and retinal locus would interact in the range of 40-80 millisecond frame times when detection becomes more difficult (see Schneider & Shiffrin, 1977, appendix D).

General Discussion

The experiments reported indicate that retinal locus in the range of 0 to 3 degrees does not interact with the type of detection task. This occurred when the main effects of processing mode and retinal locus were highly significant ($p<.0001$). The different experimental search conditions included reaction times for: consistently mapped two alternative 2:1 choice reaction time; a variably mapped comparison of one or three memory letters to one display letter; a Posner same/different match; and a comparison of two consistently or variably mapped memory set items with two display letters on twelve rapidly presented frames.

These results do not allow a conclusion that retinal locus processing is a discrete stage which proceeds the search stage. McClelland (1979) has shown that two continuous processes in cascade will not show an interaction if either the two independent variables affect the rate of two different processes, or if

one variable affects the rate of a fast process and the other affects the asymptote.

One must be cautious about extrapolating from these results beyond the fovea, or to displays in which substantial lateral interactions can occur, or to novel stimuli. The present experiments did not have sufficient power to determine if there was an interaction between retinal locus and practice. Practice has been shown to be an important factor in peripheral vision (see Johnson and Leibowitz, 1979). Since lateral interactions drop off rapidly with distance (see Eriksen and Eriksen, 1976), it is possible that retinal locus would interact with retinal interaction. This might result in experimental paradigm by retinal locus interactions when multiple letter targets are presented in close proximity (e.g., 1 degree). Since subjects have been overtrained at encoding letters, automatic encoding would be expected to be an overtrained automatic process. If subjects are asked to detect novel stimuli (e.g., Laberge, 1973) there might be an interaction between retinal locus and processing task.

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