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VISUAL SEARCH PERFORMANCE DURING SIMULATED RADAR OBSERVATION WITH AND WITHOUT A SWEEPLINE

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16. Abstract

A study was conducted to determine whether or not the presence or absence of a radar sweepline influences attentional processes and, hence, the speed with which critical stimuli can be detected. The visual display was designed to approximate an advanced, highly automated air traffic control radar display containing computer-generated alphanumeric symbols. Twenty-eight men and women, paid volunteers with no previous air traffic controller experience, were tested over a 2-hour session with half of the subjects assigned to the sweep condition and half to the no-sweep condition. Sixteen targets appeared on the screen at all times, with 10 signals (a designed change in the alphanumerics) randomly presented during each 1/2-hour of the test session. Mean detection latencies, long detection times, and missed signals all increased significantly over the task session. Although the no-sweep appeared to be generally superior to the sweep condition in all measures of detection efficiency, none of the differences was significant. Concomitantly recorded measures of saccadic eye movements revealed a pattern of change in mean fixation duration which paralleled the patterns of change in performance during the task session. However, as with performance, mean fixation durations for the sweep and no-sweep conditions did not differ, nor were individual differences in scanning activity related to performance. Possible reasons for the lack of relationship between scanning activity and performance are discussed.

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VISUAL SEARCH PERFORMANCE DURING SIMULATED RADAR OBSERVATION WITH AND WITHOUT A SWEEPLINE

I. Introduction.

Some of the current air traffic control (ATC) radar displays employ a visible rotating sweepline while others do not. Laboratory studies of eye movements during radar search have typically found that the eyes tend to move in a circular fashion when a sweepline is present and follow an irregular pattern when a sweep is absent (2,3,15,16). Gerathewohl (3) has expressed the belief that this tendency of the eyes to follow the circular motion of a sweepline may be responsible for complaints of fatigue, headache, drowsiness, and other somatic symptoms expressed by radar operators. On the other hand, a visible sweepline may have certain beneficial effects, since some controllers feel the sweepline provides a type of organization to the scanning process that is lacking in radar displays without a sweep (1).

There have apparently been no studies reported in which monitoring efficiency and/or indices of subjective fatigue are compared under radar viewing conditions with and without a sweep. The primary purpose of the present study, then, was to make such comparisons. The task employed was designed to simulate a highly automated air traffic control system in which the observer passively monitored a display containing alphanumeric symbols for infrequent but "critical" changes.

In addition to this primary purpose, several other aspects to the study were included either for exploratory purposes or for the purpose of extending the findings of our previous studies of complex monitoring. The first of these dealt with an examination of possible relations between frequency of eye movement fixations and performance. Of particular interest was the detailed examination of extreme detection latencies (maximum and minimum values) for any evidence of concomitant changes in mean fixation duration. The results of several previous studies of complex monitoring (4,12,13) suggest that maximum latencies appear to reflect lapses of attention or failures to maintain scanning, while minimum latencies provide an estimate of the individual's maximal state of alertness at any given period during the course of a monitoring session. We hoped that a measure of scanning activity would reveal whether long detection times occurred in spite of frequent scanning, or whether they were the result of an interruption in scanning. The second aspect consisted of an evaluation of the effects of increased task difficulty on monitoring performance. Two of our previous investigations (12,13) used the same basic display as that employed in the present study. However, in these earlier studies, subjects were required simply to detect and respond to a readily identifiable stimulus change (a "999" appearing in the altitude portion of an alphanumeric data block). The present study sought to determine the effects of increased information processing (the requirement to detect any change in altitude above or below designated upper and lower limits) both on performance levels and on the pattern of performance decrement.

II. Method.

Subjects. Twenty-eight university students, 12 men and 16 women, served as subjects (Ss). Half of the Ss were randomly assigned to the sweep and half to the no-sweep condition. Subjects ranged in age from 18 to 29 years. None had any prior experience with the task used nor did any have training in air traffic control. All were righthanded.

Design and Task Apparatus. All task programing and recording of responses were accomplished using a Digital Equipment Corporation (DEC) PDP-11/40 computer. The computer was interfaced with a VT-11 (DEC) 17-inch (43 cm) cathode-ray tube (CRT), which served as the S's display. The CRT was located in a console resembling an air traffic control radar unit. The stimuli (targets) consisted of small rectangular "blips" representing the locations of given aircraft. Adjacent to each target was an alphanumeric data block. Data blocks comprised two rows of symbols: the top row, consisting of two letters and three numerals, identified the aircraft, while the bottom row of six numerals indicated its altitude and speed. The first three of these numerals gave altitude in hundreds of feet and the last three gave groundspeed.

For the task condition in which a simulated radar sweepline was employed, the sweep made one complete clockwise revolution every 6 seconds. A target was updated as to location and any change in its data block moments after the sweepline passed the target's prior location. Targets normally moved in a linear fashion unless a course change was necessary to avoid target overlaps. All aspects of the no-sweep condition, including the clockwise sequence in which targets were updated, were identical to those of the sweep condition, since the no-sweep condition was obtained by simply setting the intensity of the sweepline to zero. The critical stimulus or signal to which the S was instructed to respond consisted of a change in a target's displayed altitude to a value greater than 550 or less than 150. The values of the increases or decreases in altitude were randomly determined, except that the changed altitude value could not be greater than 599 or less than 100. Ten such critical stimuli appeared in each 30-minute period; five occurred in the first 15 minutes and five in the second. The S's response to a critical stimulus consisted of pressing a button held in the right hand and then holding a light pen over the critical target. The light pen caused the altitude portion of the data block to revert to its previous value. If the S failed to detect a critical stimulus within 1 minute, the data block automatically reverted to its previous value. Marker channels on a Beckman Dynograph signaled the onset of a critical stimulus and the occurrence of the required button press. All performance data were recorded by the computer for subsequent processing.

The same target display file was used for all Ss and was initially constructed from a computer program which assigned an altitude, groundspeed, identification, entry point, and exit point to each of the targets. All assignments were randomly determined except for the following restrictions: (i) altitudes had to fall within the "normal" range of 150 to 550 (in hundreds of feet), (ii) groundspeeds had to fall within the range of 400 to 550 knots, and (iii) the entry and exit points of a given target could not be separated by less than 30° along the circumference of the simulated radar screen. In addition, time of critical stimulus occurrence and the target in which it occurred were randomly determined with the restriction that two targets could not contain critical stimuli at the same time.

Physiological Recordings and Instrumentation. Beckman miniature biopotential electrodes were attached directly above and below the right eye and at the outer canthi of both eyes. Leads from the vertical and horizontal pairs of electrodes were connected to two separate channels of the Dynograph and recorded with a 3.0-second time constant. These channels served as the two primary electro-oculograph (EOG) channels and, because of the relatively long time constant, recorded both following and saccadic movements. In order to extract only the faster saccadic movements for computer processing, the output of the primary horizontal channel was recorded on a third channel by differentiating the EOG with a time constant of 0.03 seconds. (Only horizontal movements were computer processed because of eyeblink artifacts in the vertical recordings.) The resulting positive and negative pulses were led to two Schmidt triggers set for positive and negative inputs respectively, an OR gate, and hence to one of the digital inputs of the computer. These input pulses were also displayed for monitoring purposes on a fourth channel of the Dynograph.

The computer and other recording apparatus were located in an adjacent room from which the S was visible through a one-way mirror. Indirect lighting was used in the S's room, and the level of illumination at the display was 21.5 meter-candles. This level approximates that used in operational air traffic control environments.

Eye Movement Calibration. The gain of the primary horizontal channel on the Dynograph was initially adjusted to yield a 1-mm peak-to-peak deflection to a 50-μV, 1-Hz input signal from a Grass Square Wave Calibrator. The gain controls of the Schmidt triggers were then adjusted to just fire at the peak of each positive and negative excursion of the calibration signal. Following this, each S's horizontal as well as vertical eye movements were calibrated using an optical table with chinrest support. Subjects were instructed to fixate points at 90° and 270° on the circumference of a 22-cm circle which subtended a visual angle of 20°. A similar procedure was followed for vertical eye movements, except that points at 180° and 360° were used. The gain controls of the primary horizontal and vertical channels were adjusted to yield peak-to-peak deflections of 20 mm as the eyes were deflected to the extremes of the circle. Thus, 1 mm of pen deflection equaled 1° of eye movement. Any horizontal saccadic movement equal to or greater than this value caused an output from one of the Schmidt triggers.

Procedure. On arrival the S was taken to the experimental room, orientation instructions were given, the S was instrumented for physiological recording, and eye movements were calibrated. Then a 9-point subjective rating scale was administered dealing with present feelings of attentiveness, fatigue, tension, irritation, and boredom.

The S was seated in a straight-backed chair directly facing the console. The circular display area of the screen subtended a visual angle of approximately 20° at the S's viewing distance. The minimum separation of alphanumeric targets at this distance was approximately 2.4°. Although a rigidly fixed head restraint would have been desirable in order to eliminate head movements, this was not considered feasible in view of the length of the task session. Instead, each S was instructed to sit straight in the chair with his/her head directly facing the screen at all times. While this procedure is not optimal, since small head movements produce apparent eye movements indistinguishable from true eye movements, it was expected that error resulting from head movements would be randomly distributed across conditions and within Ss. Periodic observations revealed that virtually all Ss complied with instructions to keep gross head movements to a minimum.

The task instructions emphasized the necessity of pressing the button immediately upon detection of a critical stimulus. The S was told that a critical stimulus (any altitude value greater than 550 or less than 150) could occur in any target at any time, regardless of the current altitude values of the targets. It was explained that occasional large changes in altitude would not normally occur in an actual radar system, but that this departure from normal conditions was necessary to insure that all targets would be given equal priority in scanning. Following the taped instructions, the S was given a 4-minute practice period containing six critical stimuli.

After the 2-hour task session, the S completed a second form of the subjective rating scale. This form was identical to the first except that the S was asked to rate each item, plus one additional item dealing with task monotony, on the basis of how the S felt near the end of the test period just completed.

Measurement of the Performance and Physiological Data. Performance data were computer processed and the following measures were obtained on each S for each 30-minute period (all latency measures refer to the time from critical stimulus onset to the button press):

(i) Mean response latency to critical stimuli correctly identified.
(ii) Single longest latency to a correctly identified critical stimulus.
(iii) Single shortest latency to a correctly identified critical stimulus.
(iv) Number of critical stimuli missed.

For eye movements, the computer identified each correct response (button press) and then determined mean fixation duration from the intersaccadic interval data contained in the 30-second interval immediately preceding this response. (Mean fixation duration can also be considered an index of fixation frequency. Consequently, although the data were analyzed only in terms of mean fixation durations, subsequent discussions may refer to mean fixation duration and frequency of fixations interchangeably.) If a critical stimulus was missed, the 30-second interval prior to the time the stimulus timed out was analyzed. Average values derived from the above 30-second intervals were also obtained for each 30-minute period. To eliminate various forms of electronic and/or physiological noise from the data, all apparent fixation durations of less than 100 ms were rejected by the analysis program.

III. Results.

Performance Data. Figure 1 shows mean detection latencies across 30-minute periods for all critical stimuli, as well as mean maximum and minimum latencies, for both the sweep and no-sweep conditions. Analyses of variance applied to these three sets of data revealed significant main effects for the four 30-minute periods for mean latencies, $F(3,78) \approx 7.38$, $p < .01$; maximum latencies, $F(3,78) = 4.07$, $p < .05$; and minimum latencies, $F(3,78) = 5.00$, $p < .05$. Although the data presented in Figure 1 suggest slightly faster detection latencies when no rotating sweep is employed, analyses of variance revealed no significant main effects ($p > .10$) for the sweep vs.

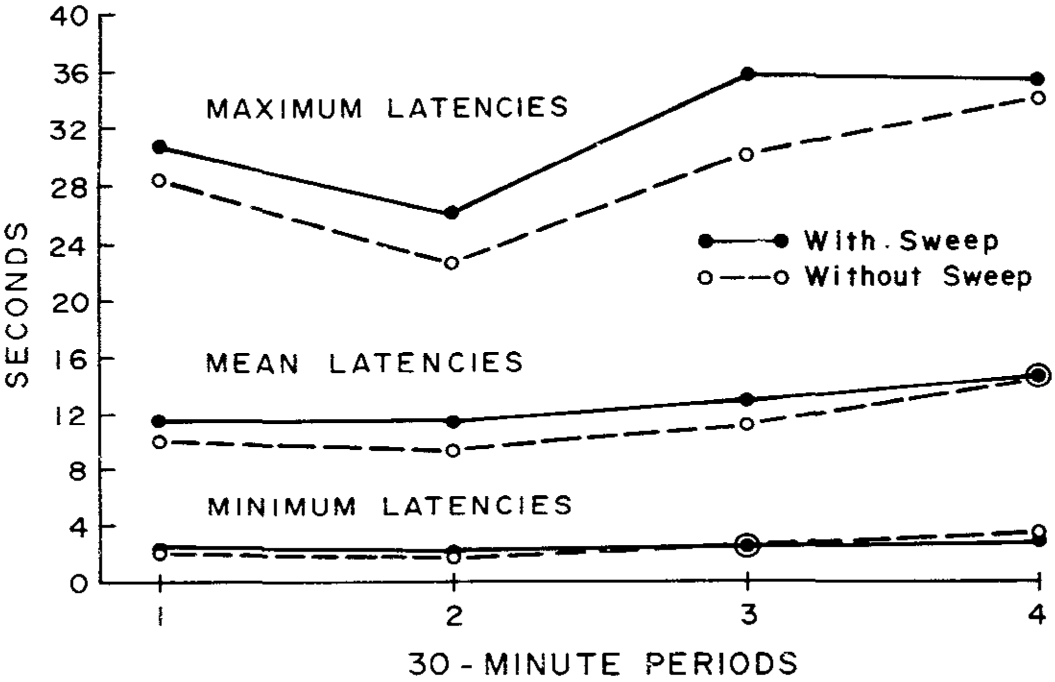

Figure 1. Mean, maximum, and minimum detection latencies for the two display conditions.

no-sweep conditions for any of the three latency measures and no significant interactions (p > .10).

With regard to missed stimuli, four critical stimuli were missed during the first half-hour, two during the second, and eight each during the third and fourth half-hours. Because of the relatively low frequency of occurrence of missed stimuli in each half-hour, these stimuli missed by Ss in each of the two experimental groups were summed over the four 30-minute periods and a chi-square test was conducted. A comparison of the number of Ss in each group missing no stimuli with those missing one or more yielded a nonsignificant chi-square of 2.33, df = 1, p > .05.

Since a secondary purpose of the present study was to examine the effects of increased task difficulty on performance, the data of Figure 1 were combined and are shown in Figure 2. Also shown in this figure are the data from our two earlier studies (12,13) for comparable experimental conditions. It is obvious that the trends across studies are virtually identical. In all three studies performance remains relatively uniform or even improves during the first hour, but becomes worse during the second. (The similarity of trends is not the result of some idiosyncrasy in the arrangement of targets, interstimulus intervals, etc. Although the same target display file was used in the two previous studies, a completely new file was created for this study.) The principal difference between the findings of the present study and those

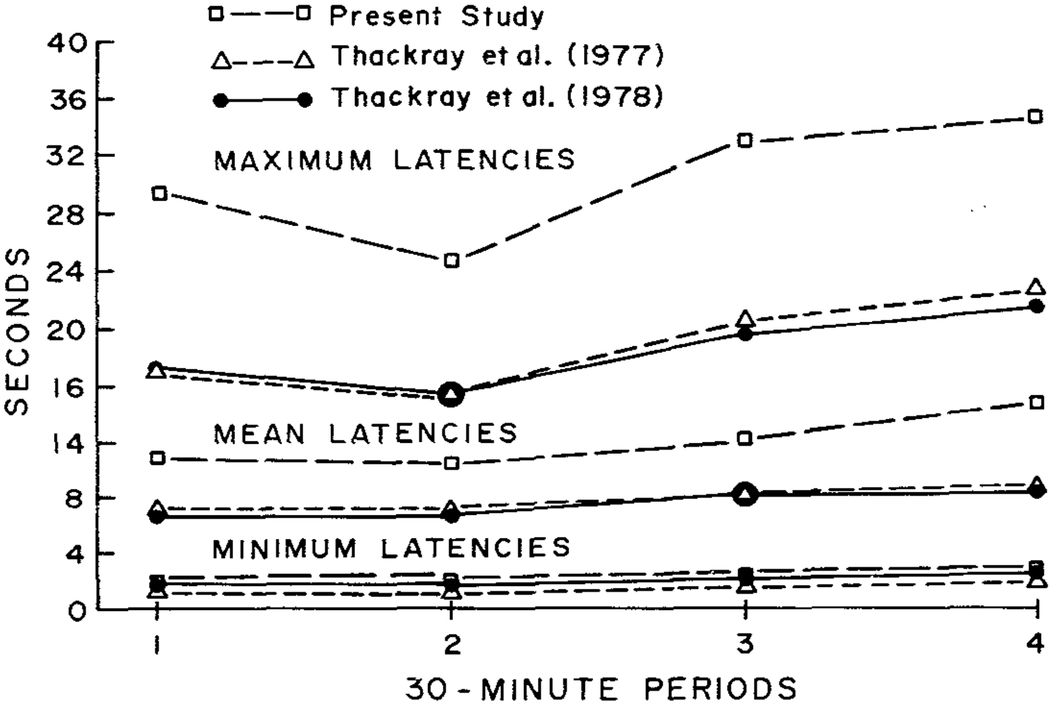

Figure 2. Comparison of the combined-group latency data of three studies.

of the two earlier ones is the greater magnitude of the obtained detection latencies. Average values across all four time periods in this study were 30.4, 12.1, and 2.4 seconds for maximum, mean, and minimum latencies respectively, while the combined data of the two previous studies yielded values of 18.8, 7.6, and 2.0 seconds for these same three measures. Thus, the requirement of the present study to detect altitude values exceeding upper and lower limits rather than the simple identification of a 999 increased detection latencies, but apparently had little or no effect on the patterns of performance change.

Subjective Data. Separate t tests applied to the rating scale data revealed no differences ($p > .05$) between the sweep and no-sweep groups at either the beginning or end of the experiment. All measures except those derived from the tension-relaxation scale changed significantly ($p < .01$) from the first to the second measurement period. Statements on the scales corresponding to the mean ratings obtained at the completion of the task period suggested that the Ss were only slightly bored, were mildly annoyed, felt more tired than usual, were reasonably relaxed, were rather inattentive, and felt the task to be very monotonous. Actual obtained mean values are not presented, since they would add nothing to the verbal descriptions just given.

Eye Movement Data. Mean fixation durations for both groups are shown in Figure 3. Analyses of variance conducted on these data revealed a significant

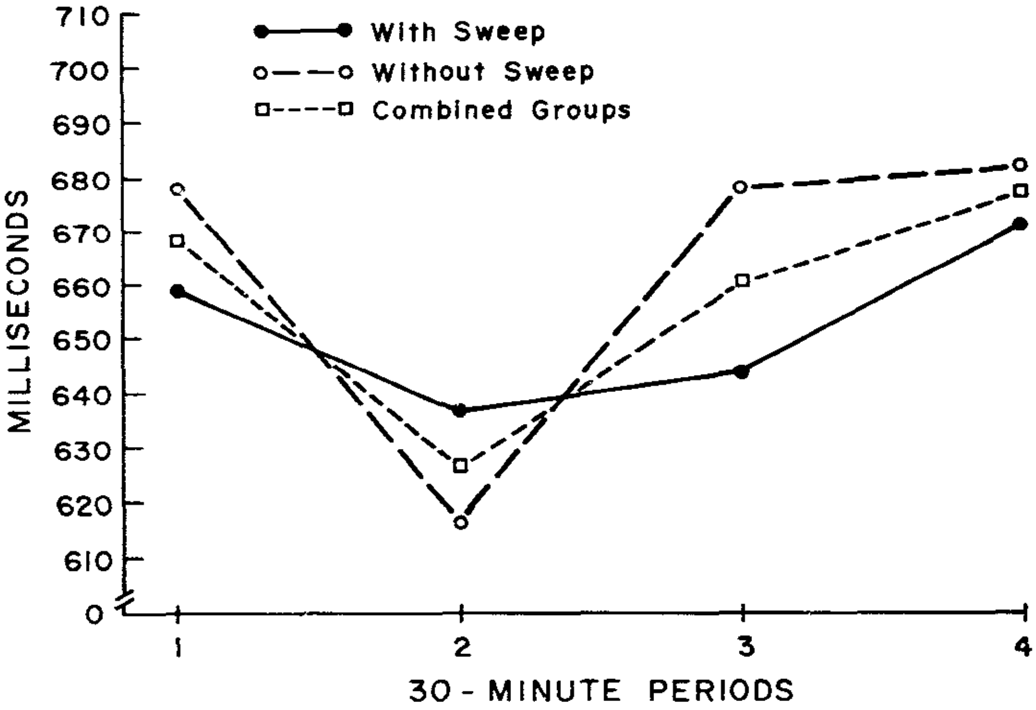

Figure 3. Mean fixation durations for horizontal eye movements.

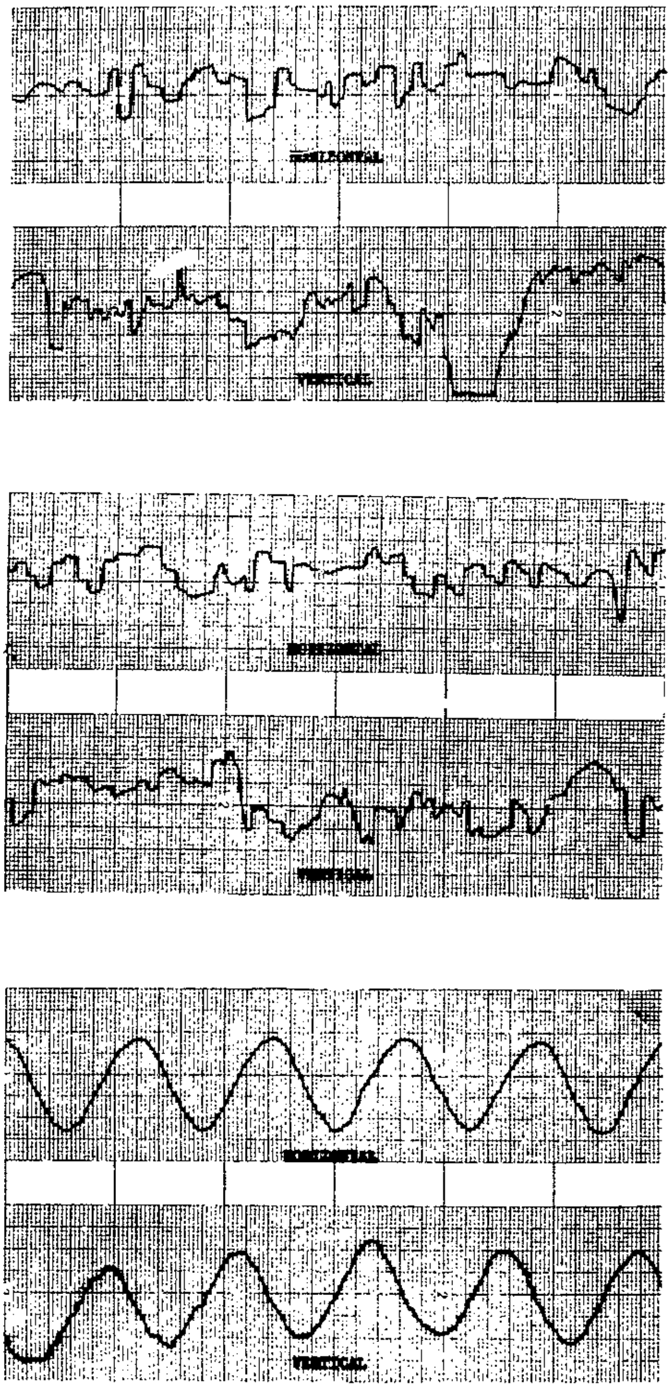

Figure 4. Sample recordings of eye movements during task performance with sweep (top record) and without sweep (middle record) compared to eye movements when instructed to simply follow the sweep (bottom record). Each record represents 30 seconds.

main effect for 30-minute periods ($F(3/78) = 5.14$, $p < .01$), but no difference between the sweep and no-sweep groups ($p > .10$) and no significant interaction ($p > .10$). Consequently, the data of both groups were combined and are shown in this same figure. It is readily apparent that the pattern of change in fixation durations resembles the performance patterns (especially maximum latencies) shown in Figure 2. A Newman-Keuls test applied to the combined data of Figure 3 revealed no differences between the first, third, and fourth 30-minute periods but all three differed significantly from the second ($p < .05$).

Scanning Patterns. Figure 4 compares the pattern of horizontal and vertical eye movements of a S instructed to simply follow the rotating sweep, with the eye movement patterns of two randomly selected Ss (one with and one without sweep) while performing the task. Each segment represents 30 seconds. Neither of the segments taken during task performance shows any evidence of the cyclic pattern present in the bottom pattern. A more precise comparison was made by examining the recordings of each S's eye movement patterns and a judgment made as to whether the S had been exposed to the sweep or no-sweep condition. Both experimenters made separate, blind judgments. Chi-square tests of the resulting frequencies were nonsignificant ($p > .05$) for both sets of judgments.

Relationship of Eye Movements to Performance. Each S's mean detection latency for each separate 30-minute period was compared with his/her mean fixation duration. No significant relationships between mean fixation duration and mean detection latency were obtained. The correlations for periods 1 through 4 were .22, -.09, -.03, and -.06 respectively ($p > .05$). Further analyses were conducted on each S's extreme detection latencies. It will be recalled that all eye movement data were obtained from the 30-second interval that preceded each detection response (button press). Thus, for each separate 30-minute period, mean fixation durations in the 30-second intervals associated with maximum detection latencies were compared with mean fixation durations in the 30-second intervals associated with minimum latencies. Separate t tests revealed none of the comparisons to be significant ($p > .05$). Average fixation durations associated with maximum and minimum latencies for the four 30-minute periods were 694 and 685, 640 and 644, 658 and 648, and 689 and 720 ms for periods 1 through 4, respectively. It is evident that there is no consistent pattern of differences in these data.

A final analysis consisted of comparing average fixation durations associated with missed critical stimuli with fixation durations associated with minimum detection latencies. The procedure was similar to that just described for maximum and minimum detection latencies. Because of the small number of missed stimuli, however, separate comparisons were not made for each 30-minute period, but only for the session as a whole. Although the mean of fixation durations associated with missed stimuli was greater than the mean of fixation durations associated with comparable minimum latencies (693 and 650 ms), the obtained t of 0.98, $df = 14$ was nonsignificant ($p > .05$).

IV. Discussion.

As noted previously, studies of eye movement patterns during radar observation have shown that the eyes generally tend to follow a rotating sweepline by means of a series of closely spaced fixations (3,15,16). These early studies, however, were attempts to simulate systems in which the primary task was frequently the simple detection of a new "pip" on the screen. Given such a task, a faint radar return might easily fade from view if the operator were not constantly attending the sweep. Thus, a search pattern in which the eyes are closely coupled to the rotating sweep would serve to optimize detection of weak signals. Under such task conditions, a circular search pattern might well produce the types of physiological symptoms described by Gerathewohl (3).

Contemporary ATC radar systems, however, typically employ a computer-generated graphic display containing a variety of alphanumeric and other symbols. In such systems, the task is not only to note the appearance of a new target, but to detect and make appropriate decisions with regard to any significant change in the alphanumeric information displayed. Given a relatively large number of targets to monitor, a great deal of information must be processed. Thus, although targets in the present study were updated in a clockwise fashion moments after the sweepline passed, it was the impression of both experimenters (who served as pilot Ss) that it was virtually impossible to process information rapidly enough by using a search pattern in which the eyes attempted to follow the sweep. (It will be recalled that the sweep made one revolution in 6 seconds.) Apparently, most, if not all, Ss in the sweep group experienced the same difficulty, since no differences were found between this group and the group that monitored without a sweepline in eye movement patterns, fixation durations, or detection latencies. Nor were there any differences between groups in perceived effort, fatigue, or attentiveness. Had the task been simply to acknowledge the appearance of a new target on the display, or had the rotation speed of the simulated radar sweepline been considerably slower, quite different results might have been obtained. However, the requirement to recognize departures from designated altitude limits appeared to approximate a realistic monitoring requirement, and the speed of sweep rotation was within the range of contemporary ATC radars. Thus, the results suggest that the presence of a sweepline neither adds to nor detracts from efficiency when the primary task consists of monitoring a complex display for the appearance of occasional, critical alphanumeric changes.

With regard to the overall changes common to both groups, the patterns of change in mean, maximum, and minimum detection latencies were quite comparable to those obtained in two previous studies using a similar radar simulation (12,13). The principal difference was the longer detection latencies found in the present study, presumably because of the increased difficulty in recognizing the critical stimulus changes. The pattern emerging from all three studies is that of relatively uniform performance during the first hour followed by a general decline during the second. Interestingly enough, the horizontal eye movement data revealed a pattern of fixation durations that appeared to parallel the patterns that have been obtained for performance. Detailed comparisons of mean fixation duration in the present study with various measures of performance efficiency, however, failed to yield any evidence of a significant covariation.

What evidence exists that might bear on the expected degree of relationship between frequency of eye movements and detection efficiency in a task of this type? Unfortunately, comparisons must be made with other types of performance tasks, since studies directly analogous to the present one apparently have not been conducted.

With regard to the general pattern of eye movements during prolonged performance, the typical finding appears to be a decline in the frequency of fixations. This has been reported during simulated driving (10), piloting a helicopter (11), and performance of a simple vigilance task (8). This decline is apparently a manifestation of fatigue (11) and parallels a decrease in performance efficiency (8).

Studies attempting to relate individual differences in the frequency of visual fixations to performance have generally reported some evidence of a positive relationship between frequent eye movements and superior performance. The findings that would seemingly be most directly applicable to the present study are those obtained from simple vigilance tasks. Schroeder and Holland (8) found high correlations between frequency of fixations and detection performance, with higher frequencies of eye movement related to higher detection rates. Similar findings were reported by Mackworth, Kaplan, and Metlay (5). However, in both studies, these relationships were obtained using a task condition in which Ss continuously monitored two or more dials. It is not very surprising that Ss whose eyes shifted more frequently between dials detected more signals. Nevertheless, other studies involving some form of visual search have also reported that frequent eye movements may be related to superior performance, although the evidence is far from conclusive. Snyder (9) found that Ss in a simulated air-to-ground search task who had lower mean fixation times detected more targets. However, the number of Ss was too small to warrant detailed statistical analysis. Thomas and Lansdown (14) reported that, out of five radiologists searching roentgenograms, the single radiologist who detected the most lesions had the shortest mean fixation durations. Schoonard, Gould, and Miller (7), on the other hand, found that good inspectors of integrated circuit chips were more rapid in locating defects than were poor inspectors, but mean fixation durations did not differ among inspectors.

Most of the evidence to date suggests some degree of relationship between frequency of eye movements and performance efficiency in visual search or monitoring tasks. The parallel trends obtained for eye movement and performance in the present study seem to support these previous findings. However, if the parallel trends do, in fact, imply a relationship, why was there no evidence of any correlation between individual eye movement data and performance?

Lack of reliability or validity of the method of recording scanning activity does not appear to be a satisfactory explanation. While only horizontal eye movements were recorded, it seems reasonable to assume that this measure would be proportional to total eye movement activity, since any scanning pattern employed in searching the display would necessarily require both horizontal and vertical movements. (It was impossible to accurately correlate horizontal with vertical eye movements in our recordings because of the contamination caused by blinks in the vertical data. Stern and Bynum (11), however, have reported that horizontal and vertical saccades covary for most Ss in a visual search task.) Reliability of the horizontal mean fixation durations proved to be quite high. An estimate of reliability based on an analysis of variance (17) of the data across 30-minute periods yielded a value of .94. Also, correlations obtained at the beginning and end of the session between hand-scored horizontal eye movements and the pulses resulting from the differentiated EOG were high (.90 and .82, $p < .01$), indicating that the data processed by the computer were reliable measures of horizontal eye movement activity. Finally, fixation durations in the present study fall within the range (estimated from their data) of mean horizontal fixation durations (641 to 943 ms) obtained by Stern and Bynum (11) for helicopter pilots during flight. They also fall within the range (430 to 1,815 ms) of total eye movement fixation durations reported by Gerathewohl (3) for radar tasks of varying difficulty.

The lack of any difference in the present study between mean fixation durations in the intervals preceding maximum detection latencies or missed stimuli and in intervals preceding minimum detection latencies suggests the hypothesis that critical targets were, at times, fixated without being "seen" as critical events, and that the number of these fixations without recognition varied in some, perhaps stochastic, manner within the session. Studies of simple vigilance performance have found that signals are frequently missed even when photographic measures of eye fixation points indicate that the S was fixating the stimulus event at the time the critical signal occurred (5,8). This has also been reported to occur in more complex tasks such as searching roentgenograms (6, p. 363) or air-to-ground surveillance (9). Virtually nothing is known concerning the frequency of occurrence of this phenomenon or the factors that may influence or contribute to it (6, pp. 362-364).

If the above hypothesis is correct, frequency of scanning (or mean fixation duration) may be a poor correlate of detection latency under task conditions similar to those employed in the present study. Whether the use of a more easily detected critical stimulus (such as the 999 employed previously) or the use of Ss with extensive radar experience (such as journeyman controllers) might have changed the relationship between scanning and performance cannot be answered with complete certainty from this experiment. The use of trained controllers might have resulted in a higher correlation between scanning activity and detection latency, since, as noted earlier, there is suggestive evidence that pilots who scan more rapidly detect more ground targets (9), and similar findings have been reported for radiologists searching roentgenograms (14). However, it should be emphasized that both of these investigations used professionals (test pilots or radiologists), and both report that Ss would occasionally fail to see targets that they had actually scanned. There is no reason to believe that air traffic controllers would be any different in this respect. We hope to conduct future studies using equipment to continuously record actual eye fixation points during monitoring performance to compare the extent of covariation between scanning and performance for different levels of critical stimulus difficulty. Such studies would provide definitive information on how frequently critical targets are fixated without recognition and on the factors (e.g., experience, age, fatigue) that may contribute to the occurrence of this phenomenon.

References

1. Bales, G. A.: To Err is Human. Paper presented at the annual meeting of the Air Traffic Controllers Association, Miami, Florida, 1976.

2. Ford, A., C. T. White, and M. Lichtenstein: Analysis of Eye Movements During Free Search. JOURNAL OF THE OPTICAL SOCIETY OF AMERICA, 49:287-292, 1959.

3. Gerathewohl, S. J.: Eye Movements During Radar Operations. JOURNAL OF AVIATION MEDICINE, 23:597-607, 1952.

4. Johnston, W. A., W. C. Howell, and I. L. Goldstein: Human Vigilance as a Function of Signal Frequency and Stimulus Density. JOURNAL OF EXPERIMENTAL PSYCHOLOGY, 72:736-743, 1966.

5. Mackworth, N. H., I. T. Kaplan, and W. Metlay: Eye Movements During Vigilance. PERCEPTUAL AND MOTOR SKILLS, 18:397-402, 1964.

6. Monty, R. A., and J. W. Senders (Eds.): Eye Movements and Psychological Processes, Lawrence Erlbaum Associates, Hillsdale, 1976.

7. Schoonard, J. W., J. D. Gould, and L. A. Miller: Studies of Visual Inspection. ERGONOMICS, 16:365-379, 1973.

8. Schroeder, S. R., and J. G. Holland: Operant Control of Eye Movements During Human Vigilance. SCIENCE, 161:292-293, 1968.

9. Snyder, H. L.: Dynamic Visual Search Patterns. In Visual Search, National Academy of Sciences, Washington, D.C., 1973.

10. Stern, J. A., A. Beideman, and S. C. Chen: Effect of Alcohol on Visual Complex Task Performance. In M. Horvath (Ed.), Adverse Effects of Environmental Chemicals and Psychotropic Drugs: Neurophysiological and Behavioral Tests, Vol. 2, Elsevier, New York, 1976.

11. Stern, J. A., and J. A. Bynum: Analysis of Visual Search Activity in Skilled and Novice Helicopter Pilots. AEROSPACE MEDICINE, 41:300-305, 1970.

12. Thackray, R. I., J. P. Bailey, and R. M. Touchstone: The Effect of Increased Monitoring Load on Vigilance Performance Using a Simulated Radar Display. FAA Office of Aviation Medicine Report No. AM-77-18, 1977.

13. Thackray, R. I., R. M. Touchstone, and J. P. Bailey: Comparison of the Vigilance Performance of Men and Women Using a Simulated Radar Task. AVIATION, SPACE, AND ENVIRONMENTAL MEDICINE, 49:1215-1218, 1978.

14. Thomas, E. L., and E. L. Lansdown: Visual Search Patterns of Radiologists in Training. RADIOLOGY, 81:288-292, 1963.

15. Wallis, D., and J. A. Samuel: Some Experimental Studies of Radar Operating. ERGONOMICS, 4:155-168, 1961.

16. White, C. T., and A. Ford: Eye Movements During Simulated Radar Search. JOURNAL OF THE OPTICAL SOCIETY OF AMERICA, 50:909-913, 1960.

17. Winer, B. J.: Statistical Principles in Experimental Design. McGraw-Hill, New York, 1962.

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