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VISUAL SAMPLING ON A SIMULATED DIMUS-TYPE DISPLAY

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PREFACE

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Experienced sonar operators were used to study the visual search on a simulated DIMUS display. The electro-oculargram was used to estimate the location and amount of time spent in each eye fixation on the display made while the operators searched for targets. The data obtained were analyzed to determine (1) the eye movement parameters, (2) the visual coverage of the display, and (3) the relation between operator attention to areas on the display and the display data in those areas.

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It was found that the operator search of the display is not only nonuniform, but it is also incomplete. The operator viewing time was not uniformly distributed across the display, and, on most presentations, some areas of the display were not even fixated. Thus, the probability of target detection depends on the target location on the display.

Average mark density over several columns was the predominant parameter that attracted operator attention. The average mark density was highly correlated with viewing time in the columns, although a target appeared in only one column.

Nonfoveal as well as foveal vision is used in searching the display; so it must be designed so that it can be seen effectively through both kinds of vision.

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VISUAL SAMPLING ON A SIMULATED DIMUS-TYPE DISPLAY

INTRODUCTION

It has been shown that a sonar operator does not sample a display uniformly.[1,2] His attention will be concentrated in some areas of the display, but other areas are not sampled at all. Since the operator does not sample uniformly, we must know what sampling pattern he does use in order to determine his visual search characteristics.

This report discusses the visual search of three experienced sonar operators observing a DIMUS display. The specific goals are to

- determine the visual coverage of the display,
- evaluate the visual coverage, and
- relate the visual sampling to data on the display.

BACKGROUND

The areas a sonar operator samples on a display can be determined from his eye fixations. He obtains visual data while his eyes are fixated and not during the rapid eye movements (saccades) between fixations. Visual acuity decreases in areas away from the fixation point, with the maximum occurring inside of a visual angle of approximately ± 1 deg. In this report, data within this angle (the angle of foveal vision) will be considered to have been sampled. Thus, a record of a sonar operator's eye fixations, obtained from his electro-oculargram (EOG), can be used to determine the foveal sampling on the display.

A record of visual sampling by operators can be used to determine the visual coverage of a display. For this study, areas of a display covered by the foveal vision are considered sampled; areas not covered are considered missed. Therefore, a plot of the display area showing the fixations can be used to determine visually sampled and visually missed areas.

The method discussed in this report was used successfully to study experienced sonar operators' visual coverage in searching a PPI display.[1] Targets were indicated on the display by a high-intensity mark at a single location, instead of by a target track as on the DIMUS display. The noise background was a uniform noise field over the display area having no attention-attracting features. It was found that the operators did not sample the PPI display uniformly and that their respective visual coverage varied greatly. There is a relation between these variations and target detection capability.

AREAS OF VISUAL CONCENTRATION

The current perception theory assumes that visual information is obtained sequentially. On a complex display, areas are fixated successively by the viewer, and the heaviest concentration of fixations is on the most important elements of the display. This was shown by Yarbus[3] in his study of eye fixations on paintings. He found that attention to areas of a painting depended on what the viewer was asked to consider. When told to look at a painting with no questions in mind, most observers directed their attention to faces. However, when asked about the economic conditions of the subjects in the painting, much attention was directed to the room furnishings and clothing in the picture. In each case, when later questioned about the painting, the observer's knowledge was limited in those areas he had not fixated heavily.

On the basis of the current perception theory and the findings of Yarbus, the eye fixations of a sonar operator should be concentrated on the most important areas of the display. (The amount of viewing time spent in a particular area of the display is considered the measure of its importance.) Since the operator is trying to detect a target, he should concentrate on areas where a target is most likely to appear. If he is told a target can appear anywhere, he should cover the display uniformly, because targets appearing in neglected areas are more likely to be missed than those in areas of concentration.

DETERMINING EYE FIXATIONS

Eye fixations are obtained from the operator's EOG. This procedure, which is based on measuring the electric field around the eyes, was described in the PPI study[1] and will be described only briefly here. As the eye rotates in its socket, the electric field around it varies in proportion to the angle of movement. The field can be measured by placing electrodes on the skin around the eyes. Then, by properly calibrating the measurement system and ensuring that the operator's head remains in a fixed position, the fixation point of his eyes on the display can be determined.

Errors resulting from the use of the EOG measurements are caused mainly by electrode drift and, to a lesser extent, by head movements. Drift can be canceled by determining the error when the operator looks at a known point and subtracting the error from the EOG. Errors can also be reduced by making a suitable estimate of other fixation points. The procedure to estimate fixations is to record the EOG on magnetic tape, digitize it, and analyze it on a general-purpose digital computer, as described in the following section.

THE EXPERIMENT AND DETERMINATION OF FIXATION POINTS

SUBJECTS

The three subjects used in this study were all experienced sonar operators, who were either currently assigned to a Fleet Ballistic Missile (FBM) submarine or had just completed such an assignment. Each had recently completed a patrol in an FBM as a sonar operator.

PROCEDURE

Each of the three experiment sessions lasted approximately 1 to 1-1/2 h. The first 10 min of each session was used to apply electrodes to the skin around each subject's eyes. Approximately 10 to 15 min was required for the electrodes to stabilize. While waiting, the operator was told how his eye movements were to be measured, he was read the instructions (appendix A), and was shown a typical presentation on the display. Approximately 1 hr was required for the 20 presentations, each of a maximum duration of 78 sec.

A typical presentation would start after the operator had settled his head into the head rest. A dot would then appear at the center of the display for him to fixate. While he fixated, the system was zeroed so that zero corresponded to the center of the DIMUS display[4]; the display data presentation would then begin. When the operator decided there was a target, he called, "Stop." The display data were removed and a dot was again presented at the center of the display for him to fixate. Then the same display data were returned so that he could identify the target. The experimenter would adjust a cursor over the target column indicated by the operator. Second- and third-choice targets were indicated in a similar manner. The display would then be made blank and the operator allowed to relax approximately 20 sec before the next presentation was begun.

THE DISPLAY

The marks on the DIMUS display were generated from a pseudorandom noise generator so that those in any column were generated on the basis of a binomial process, providing a 0.50 probability that a mark would appear. A typical display presentation is shown in figure 1. There are 48 columns, and as many as 85 rows can be displayed. The rows appear sequentially from the top beginning with row 1. When row 2 appears, row 1 moves down one space; when row 3 appears, rows 1 and 2 move down; and so on. This procedure continued during the experiment until either the operator called a target and the display was stopped or until all 85 rows appeared. A full presentation required approximately 78 sec; 73 sec to generate the 85 rows followed by 5 sec of static presentation. A target column was defined as the one having the most marks when the display was stopped.

The DIMUS presentation covered a maximum area of 16.5 by 13.8 cm on the display oscilloscope and the operator's eyes were 33 cm from the face of the display. These dimensions correspond to a horizontal visual angle of 38 deg and a maximum vertical visual angle of 24 deg.

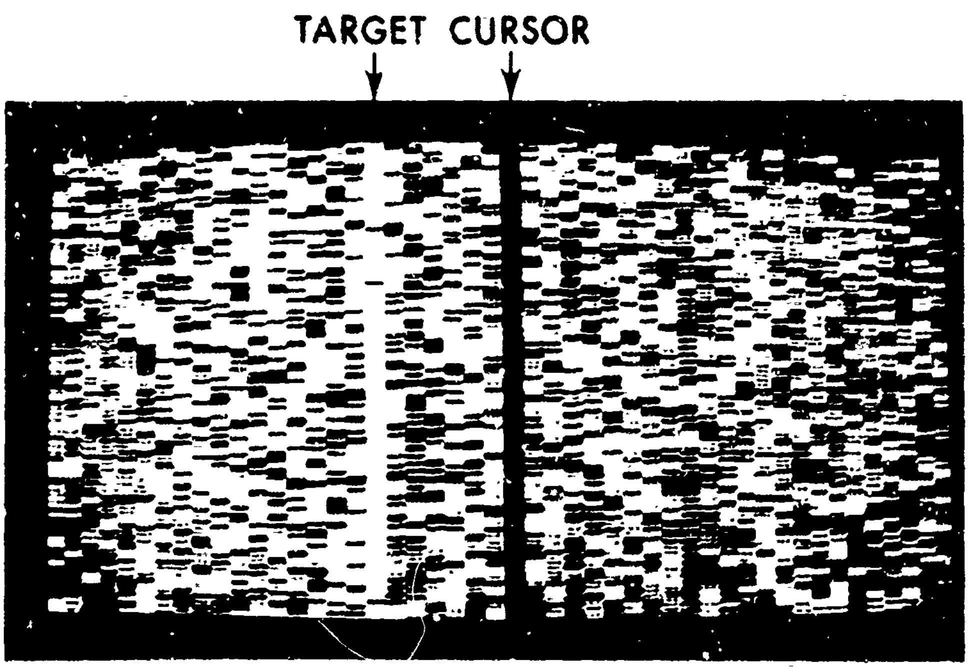

Figure 1. DIMUS Display Presentation

ESTIMATING EYE FIXATION POINTS

All calcul .tions made to estimate the eye fixations of an operator used the visual angle to locate fixation points. Since all distances were constant and changes in fixations were made by eye rotations, the visual angle contains the information required to locate the fixation. Also, since the foveal vision subtends approximately 2 deg of solid angle, this method of determining foveal coverage of the display is the most convenient.

The first processing step was to digitize the recorded EOG data. (A block diagram of the analog-to-digital (A/D) conversion is shown in figure 2.) Only the data recorded while the display was on for target detection were digitized. No conversion or analysis was done for data recorded while the display was on for the operator to indicate selected targets. The digitized data were stored on magnetic tape so the remaining steps of the analysis could be accomplished using a general-purpose Univac 1108 digital computer.

Next, errors in the EOG were corrected using the system shown in figure 3. The error is the difference between the value of the fixation point calculated from the EOG data and the correct value for a known fixation point. Correction was made by subtracting the error from each sample; a straight-line approximation was used for correction between the known fixation points. This process provides a reasonably error-free signal from which the estimate of the fixation angle can be made.

Finally, the fixation angle was estimated from the corrected EOG according to the amount of change in the electrical signal. The first digital sample was considered to be the first estimate of the angle, and then the difference between the estimate and the second sample was considered. If the difference was less than 1 deg, the second sample was averaged with the estimate, and the difference between the third sample and the average was considered. This process was continued until a sample point was found that differed from the estimate by more than 1 deg. When this occurred, a new estimate was begun using the new point as the first estimate. Thus, each estimate of the visual angle consists of the average of all the sample points that differ from the average by 1 deg or less, and all changes in fixation points are greater than 1 deg. This estimating procedure acts like a lowpass filter, since it removes high frequency components; however, the rapid change of fixation points, characteristic of eye movements, is retained.

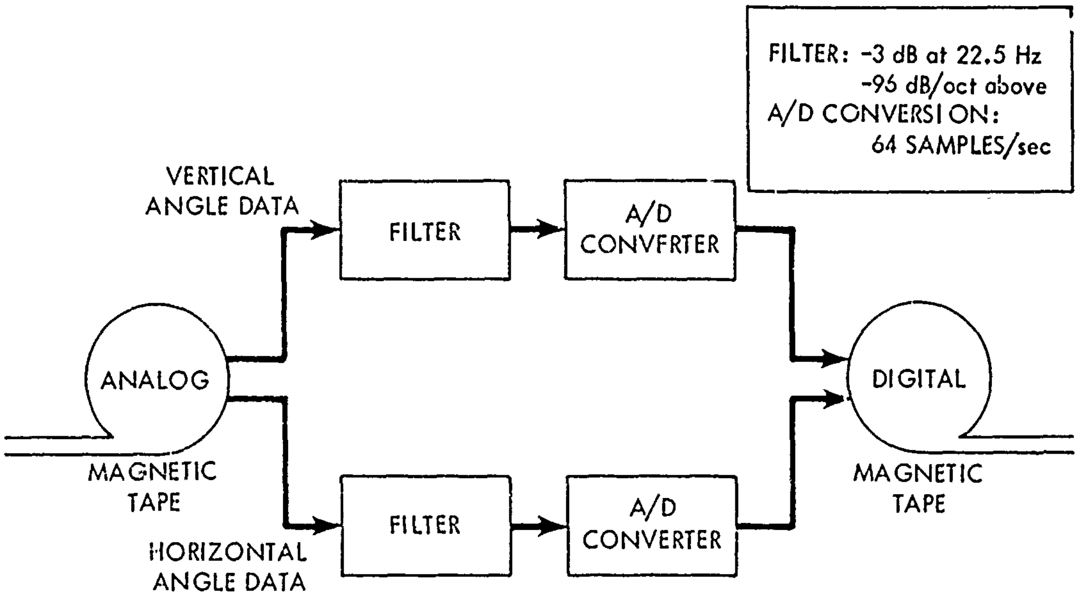

Figure 2. Block Diagram of A/D Conversion System

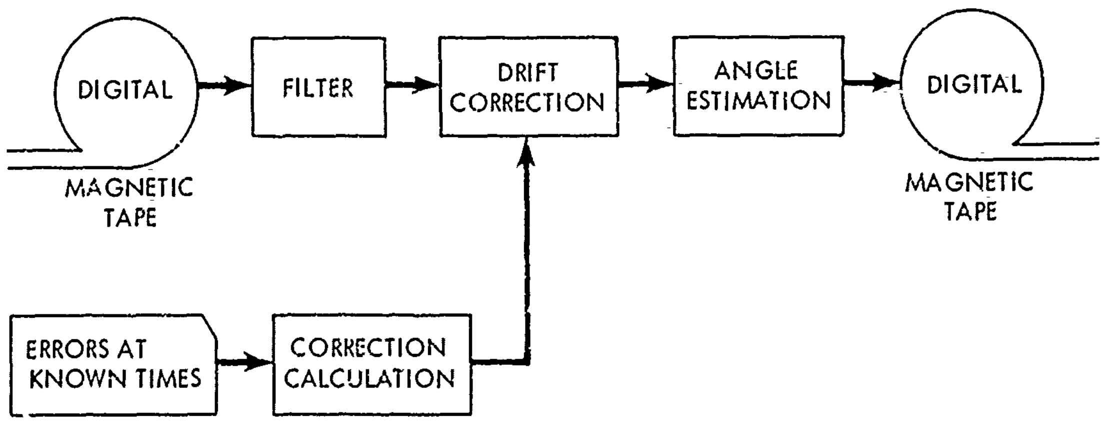

Figure 3. Block Diagram of Data Reduction System

The above procedure, using 1 deg as the maximum difference in the estimate, was chosen for several reasons: First, the foveal vision covers approximately 2 deg of visual angle; so ±1-deg changes are within the foveal angle. Second, we are only interested in the foveal fixation point on the display, but the eye makes continual small moves around the fixation point; so these small movements are averaged out. Third, low-level, high frequency noise is eliminated. Finally, the storage requirements in the computer are reduced, since only the value of the estimate, the starting point, and the final point need be stored, and not all of the data points in between.

RESULTS AND DISCUSSION

Analysis of the experimental data was done by digital computer. The analysis is based on the estimate of the location and length of fixation and the regeneration of the display data presented to the operator. The results of the analysis were divided into three parts:

- Analysis of eye movements: length of fixations and the magnitude and direction of the moves.
- Visual coverage of the display: a consideration of the areas not fixated on the display, their location and relation to order of appearance, and time spent fixating regions of the display.
- Correlation of fixation times with data on the display presented to the operator.

All results were obtained from the same three operators.

EYE MOVEMENT PARAMETERS

The eye movement parameters considered are the length of fixations, and the magnitude and direction of the eye movements. These parameters are considered to be independent of location on the display, the length of the run, and the data presented on the display.

Since saccades take a definite amount of time, the samples of the digital sampler contain points obtained during the saccades. The average move for the three operators combined was approximately 4.1 deg. According to Yarbus,[3] the time to make a 4 1-deg saccade is approximately 0.035 sec. Since the digital sampler makes 64 samples/sec, at least 2 samples would be obtained during the time to make an average move. The estimating procedure described above will include these values in the output of the estimates of fixation points as one-sample-long fixations. However, since these single samples are not part of any fixations, but a result of the time to make the saccade, they should not be considered as fixations, and not included in fixation times. The single samples are excluded from figures 4, 5B, 6, and 7.

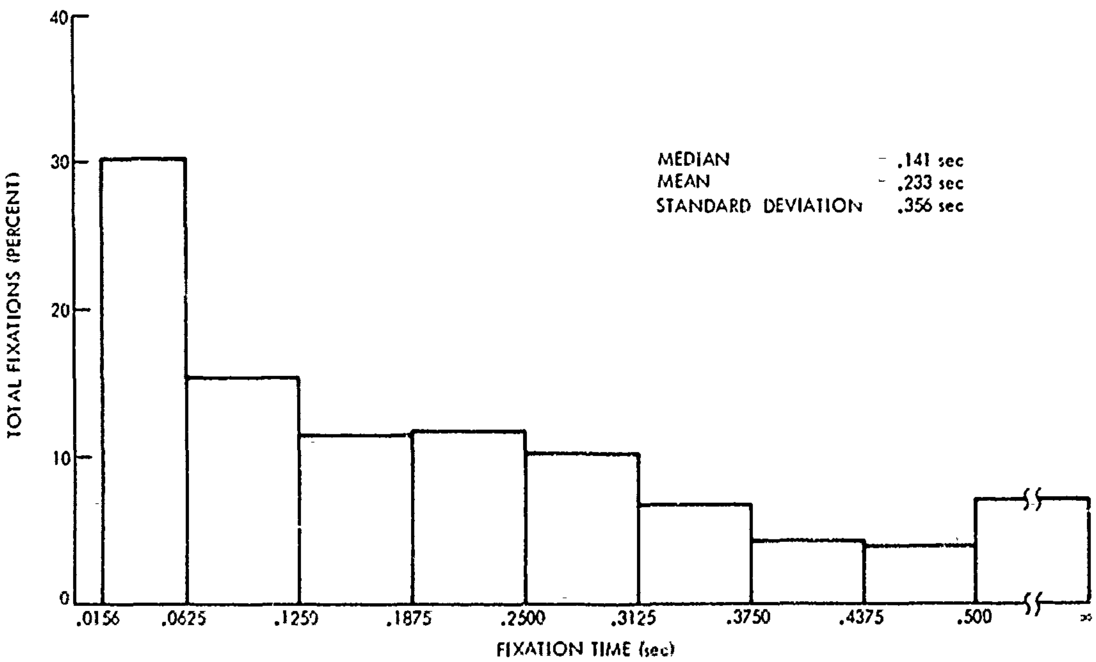

Figure 4. Histogram of Fixation Times

Fixation Times

Figure 4 is the histogram of the fixation times for the three operators combined. The figure shows that, in general, the number of fixations decreases with increasing fixation length, with about 7 percent of the total number of fixations greater than 0.5 sec. The average fixation time for the three operators was 0.233 sec (standard deviation 0.356 sec).

Figure 5A shows the apportionment of time by the three operators. In this figure, the time interval 0 to 0.0156 sec represents samples taken during saccades; so approximately 7 percent of the total time was spent in making saccades. Since the operator cannot see the display while making a saccade, a minimum of 7 percent of the total viewing time was lost in making eye movements.

The abscissa of figures 4 and 5A are drawn to the same scale so that these figures can be compared. In the range from 0.0156 to 0.3125 sec, the relative amount of time spent in fixations of a given length increases with the fixation length; however, the number of fixations in this inverval decreases with increasing fixation length. In the time interval from 0.25 to 0.5 sec, both the relative amount of time and the number of fixations decrease with increasing fixation length. A large percentage of time is spent in a few relatively long fixations. Over 30 percent of the total time is spent viewing the display in fixations 0.5 sec and longer; yet these fixations represent less than 7 percent of the total number of fixations.

Figure 5B gives the distribution of time spent in fixations on the display. The 0- to 0.0156-sec saccades time is not included in this figure so that only the fixation times are considered. This figure shows that the most time (36 percent) is spent in fixations ranging from 0.25 to 0.5 sec long. However, consideration of figure 5A shows that more time (43 percent) was actually spent in fixations ranging from 0.125 to 0.375 sec long. Thus, fixations ranging from 0.125 to 0.375 sec long are used most in the actual viewing of the display.

Magnitude and Direction of Movements

Figure 6 is a histogram of the magnitude of eye movements for the three operators combined. The 1-deg and smaller moves are not shown in this figure since they are removed by the estimating procedure discussed above. The number of moves observed decreases exponentially with the length of the move, with less than 5 percent of the moves greater than 15 deg. The moves indicated from 23 to 26 deg are probably the result of blinks, since blinks cause large deflections.

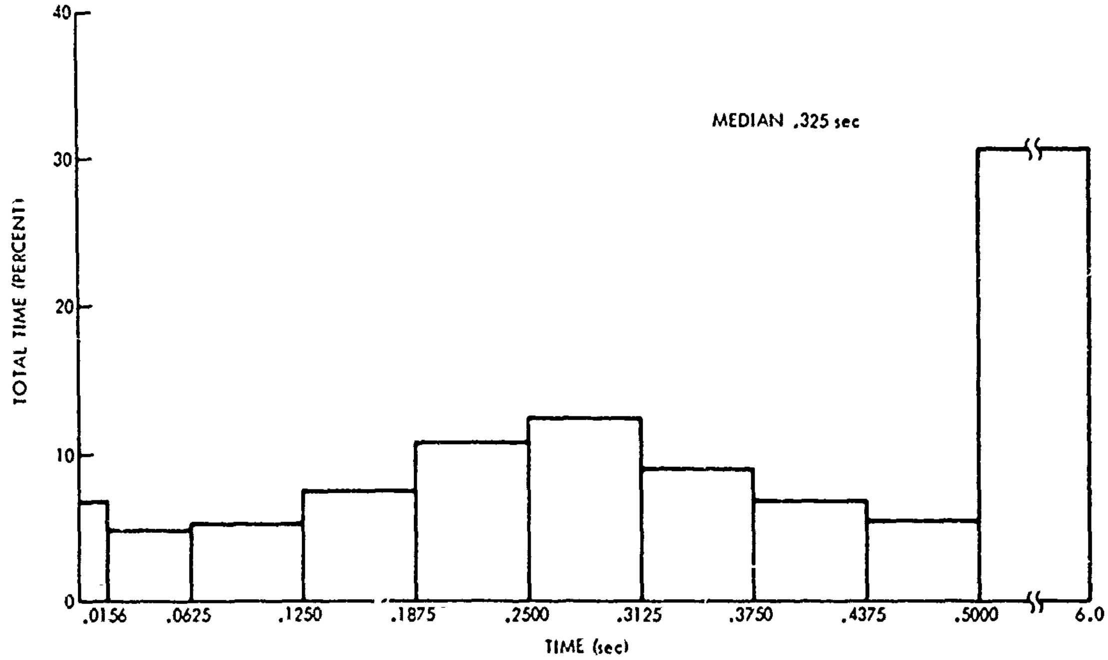

Figure 5A. Apportionment of Total Viewing Time

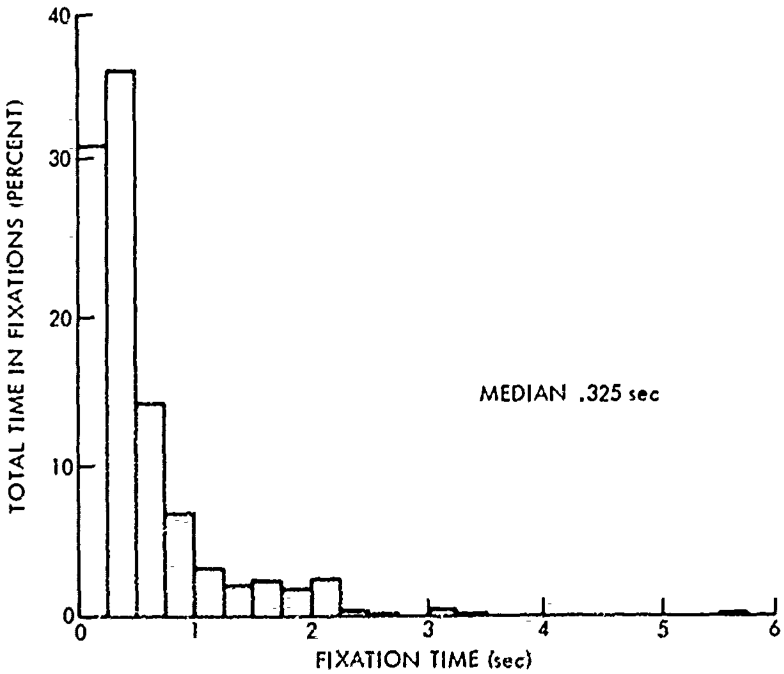

Figure 5B. Distribution of Fixation Times

Figure 5. Apportionment of Viewing Time in Fixations, Three Operators Combined

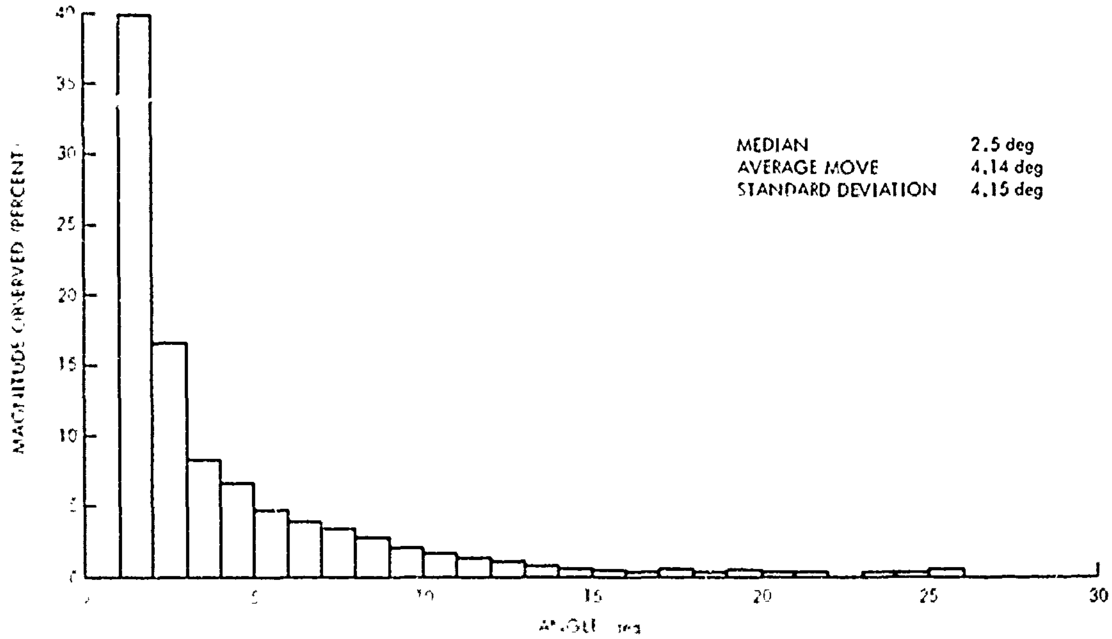

Figure 6. Histogram of Eye Movement Magnitudes

Figure 7 gives an example of the magnitude and direction of an operator's eye movements while looking at the display. The magnitude is the angle of eyeball rotation during the saccade, and the angle in the figure is the direction of the move (right is 0 deg, left is 180 deg, up is +90 deg, down is -90 deg). In this figure, the one-sample estimates have been removed, and the magnitudes shown are included in the calculation of the histograms in figure 6.

The process typical for all the operators when making eye movements is apparent in figure 7; large saccades are usually followed immediately by short saccades. This process of making a large move followed by several short moves is a characteristic of eye movements.[5]

After their initial eye adjustments to look at the starting presentation, the operators made no vertical moves for a relatively long time. For example, in figure 7, after the first move at t = 0 to start looking at the developing presentation, there were no vertical moves for the first 14 sec. (Vertical moves are indicated in this figure by an angle of ±90 deg for the movement.) During this time, the display was building up from a height of one row to 16 rows subtending approximately 4.5 deg. After about 20 sec, when 24 lines were on the display, vertical moves appeared in significant numbers. Considering all presentations to the three operators, vertical moves did not occur until the display had grown vertically to an average size of 3.6 deg (standard deviation 1.1 deg).

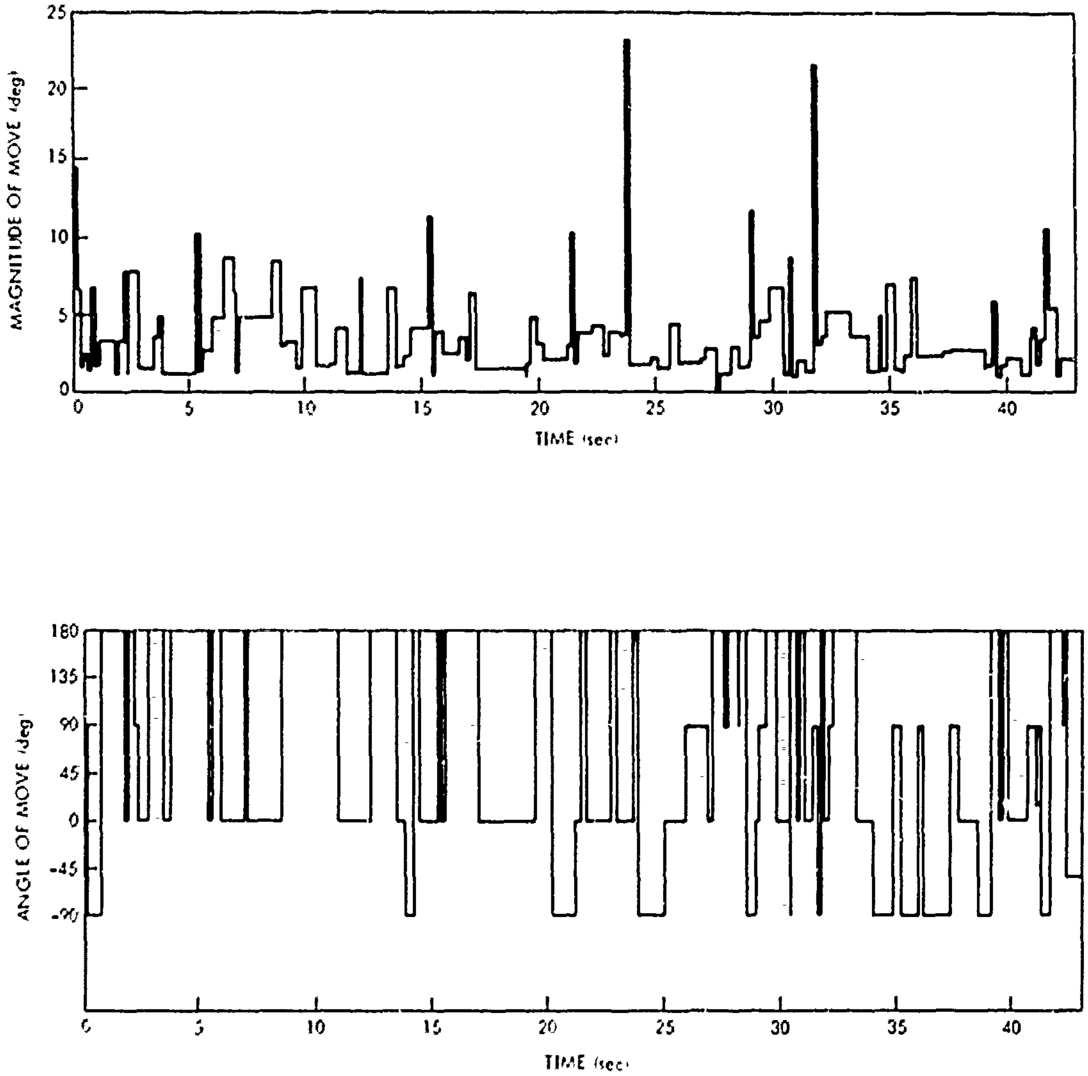

Figure 7. Example of the Magnitude and Angle of Each Change in Fixation on One Presentation
(A diagonal move is at any angle other than 0, ±90, or 180 deg.)

Most of the eye movements made by the operators observing the display were either up and down (vertical) or left and right (horizontal). (No diagonal moves are apparent in figure 7.) Table 1 shows that almost 95 percent of the moves were vertical or horizontal; only 5.3 percent of the moves were made diagonally across the display (off axis). However, the diagonal moves tended to be larger; 5.94 deg off axis versus 4.04 deg on axis.

There is a relatively large difference in the up and down moves. The downward moves tend to be smaller than those made upward, but there are many more moves made down than up. The moves made to the left and right have about the same average magnitude, and there is a relatively small difference in the number of moves (less than 1 percent).

Table 1. Direction and Magnitude of Eye Movements for Three Operators

Number of Moves	Percent of Total Moves	Average Magnitude (deg)	Variance (deg^2)	Standard Deviation (deg)	Movement
2,743	21.9	4.63	22.04	4.69	Up, +90°
3,914	31.3	3.29	11.22	3.35	Down, -90°
2,636	21.1	4.23	17.72	4.21	Left, 180°
2,549	20.4	4.35	19.51	4.42	Right, 0°
11,842	94.7	4.04	16.96	4.12	On Axis
662	5.3	5.94	21.60	4.65	Off Axis
12,504	100	4.14	17.21	4.15	Combined

Discussion

The analysis of the eye movements (fixation length, direction of moves, etc.) has been included for several reasons. Studies of eye fixations in visual search usually give eye movement parameters. Many results in a study of visual search are related to the display used, so the eye movement parameters may be the best basis for comparison of different studies. A new process for estimating the fixations is used in this report, so a comparison with other studies should be made. Finally, the eye movements themselves are of interest.

The 0.23-sec average fixation time found here is smaller than values reported in some other studies. Ford, White, and Lichtenstein[5] gave a mean fixation time of 0.28 sec for free search, and White and Ford[6] found a mean fixation time of 3.7 sec for a simulated radar search. The Dunlap and associates study[2] of the visual search of sonar operators reports a mean fixation time of 0.32 sec. It has been reported that the duration of fixations increases with decreasing display size.[7] However, the above differences in fixation times could have been caused by the use of different lowpass filters. The lowest cutoff filter gives the most averaging and tends to average out the short fixations. The 0.28-sec average was determined from data filtered at approximately 10 Hz. The 0.32-sec average was a result of data that had been passed through a lowpass filter with an even lower cutoff frequency. The 0.23-sec average fixation given in this report is for data filtered at 22.5 Hz. Whether there are differences caused by the various formats is impossible to tell from these data.

Figure 5, the percentage of total time by fixation lengths, indicates the fixations used in viewing the display much better than the histogram of fixation times. The actual time spent during a few long fixations is more than equal to the time spent in many short fixations. A consideration of the histogram of fixation lengths would indicate that the short fixations are most important since there are so many of them. However, the fixation times ranging from 0.1 to 0.4 sec are actually the most significant, since they represent the most time used in observing the display.

The direction and magnitude of the operator's changes in fixation points indicates how the operator is looking at the display The equal size and number of left and right changes shows that the operators are not looking at the display as they would a book. If they looked at the display as in reading, there would be fewer moves to the left than to the right, and the moves to the left would be longer than the moves to the right.[3] However, there are approximately the same number of moves to the left as the right, and the sizes of the left and right moves are not significantly different. The vertical moves indicate the operator is scanning columns from top to bottom. Fewer moves are up than down, and the upward moves are much larger than the downward.

It has been reported that the lengths of saccades increase as the visual angle subtended by the display increases.[7] The average eye movement here for the three operators combined was approximately 4 deg (one-sample estimates eliminated). Ford, White, and Lichtenstein[5] report a mean movement of 8.6 deg on a display subtending 30 deg of visual angle. The Dunlap and associates study[2] of sonar operator visual search gives a mean of 2.4 deg for a display subtending 19 deg of visual angle. Since the display used here subtended 28 deg by 23 deg maximum, the average move and the display size appear to be related. However, the differences may also be caused by different interpretation of the data, since the 2.4- and 4-deg mean eye movements were determined from measurements obtained directly from ink records of the filtered eye movements, and there is no way of knowing how small eye movements were included in the average.

The absence of vertical moves during the first part of the presentation gives an indication of the visual angle the operator is using to view the display. When the display subtended less than 4 deg vertically, the operator tended to make horizontal moves only. If the operator were relying on the 2-deg foveal vision for viewing, then vertical moves on the order of 2 deg in magnitude should have been occurring. Thus, the visual angle used by the operator must be approximately 4 deg, since he did not have to make vertical moves to view the display when it was smaller than this value.

OPERATOR COVERAGE OF THE DISPLAY AREA

The eye fixations were analyzed to determine the distribution of viewing time and the location of unfixated areas on the display. From this information, the operator's assessment of the importance of particular areas on the display for target detection was determined and his visual coverage evaluated.

The amount of time a particular area is viewed is considered to be an indication of the relative importance of that area for target detection. In this study, areas fixated for the longest time are assumed to be the most important, and those fixated for the shortest times, the least important.

Display data from the unfixated areas are not sampled through the foveal vision and are not as important to the operator for target detection as data from fixated areas. The location of unfixated areas is considered in the analysis because a target appearing there is more likely to be missed than is a target in a fixated area.

Visual Coverage

Figure 8 provides an example of an operator's visual coverage of the display during the presentation shown in figure 9. (The data in figure 7 are also for this presentation.) The eye fixation points are at the center of the circles shown in figure 8. These circles, which represent 2.5 deg of visual

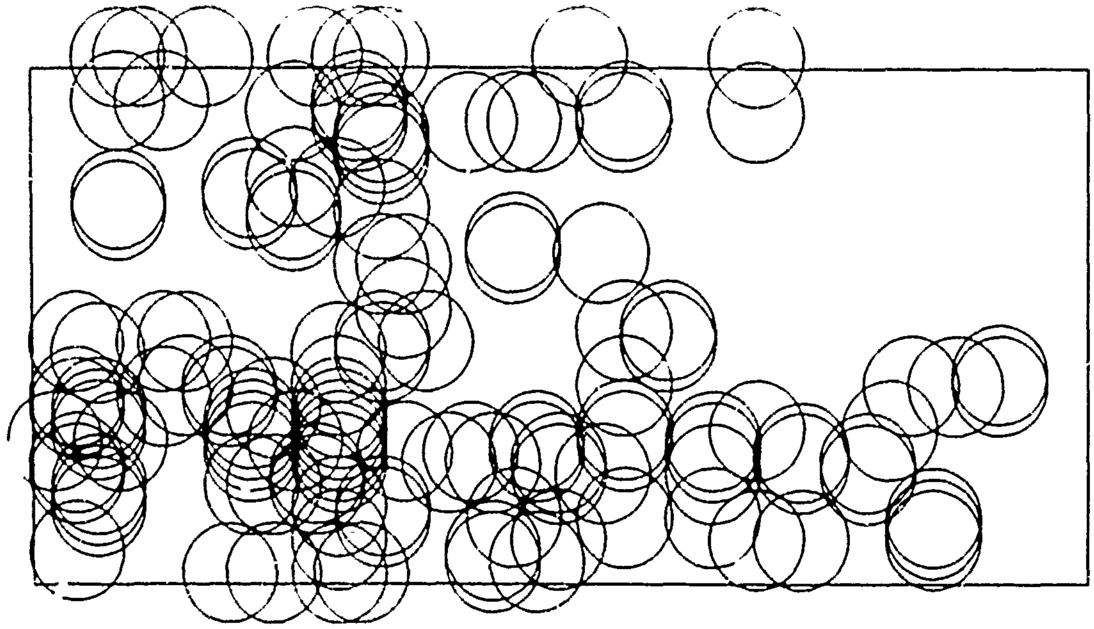

Figure 8. Visual Coverage of a Presentation

coverage on the display, are larger than the 2-deg foveal coverage to allow for error in determining the fixation points. Figures 8 and 9 represent a 40-sec presentation, in which 47 rows appeared on the display.

The nonuniform visual coverage of the display that is shown in figure 8 was typical for the operators involved in the experiment. As can be seen in the figure, some areas were not included in the search through the foveal vision and others were heavily fixated. Data in the upper right side of the display were never viewed directly, whereas the left side had many fixations.

Given the above results, it is important to determine whether some areas of the display are consistently more likely to be unfixated than others and to determine the distribution of viewing time across the display. The following results and discussion will attempt to answer these questions.

Analysis of Display Coverage

In order to obtain quantitative results, the display area was divided into equal parts (domains) and analyzed with respect to the amount of viewing time in each part. The domains consist of an area 6 columns wide and 12 rows high (having visual angles of 3.5 and 3.3 deg, respectively). This size was chosen to fit the display dimensions and still have approximately equal vertical and horizontal visual angles. Only areas including whole domains were analyzed, i.e., parts of domains were excluded. Figure 9 shows a presentation divided into domains for analysis; the 10-row area at the top of the display was excluded from the analysis because it represents a group of partial domains.

Files and bands are used in the analysis. A file consists of a vertical column of complete domains; e.g., there are 8 files shown in figure 9, each consisting of 3 domains. Bands are horizontal groupings of 8 domains that extend across the display; e.g., there are 3 bands shown in figure 9.

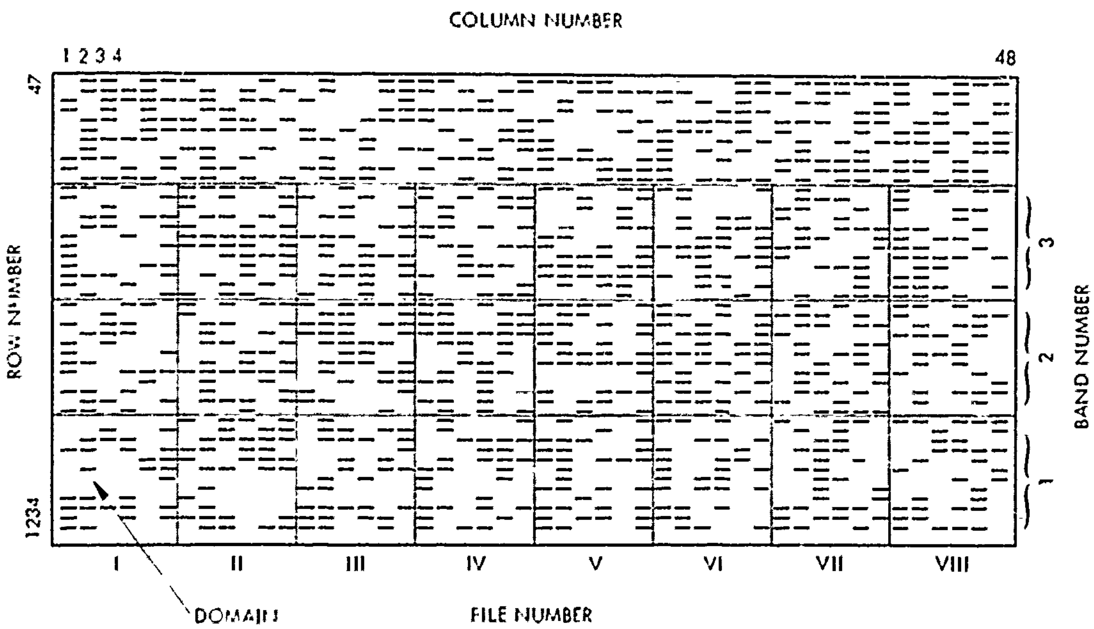

Figure 9. Computer-Regenerated Display Data

The analysis in this section is based on the operators' total viewing time in each domain on the display. If the total viewing time in a domain was less than 0.1 sec in a presentation, then the domain is considered to have been missed on that presentation. A total of 57 presentations for the three operators are analyzed; the three exclusions represent two presentations with less than 12 rows, and one presentation which was not recorded properly. Appendix B shows which domains were viewed and which ones missed on each presentation. The figures in appendix B are summarized in appendix C, which gives the number of presentations in which each domain was missed.

Nonparametric statistics was used to analyze all data so that few assumptions about the underlying distributions must be made.[8] Since the correlations are based on ranking data rather than on the actual data values, large changes in data values produce the same ranks as do small changes and, therefore, have no effect on the correlation. For instance, in figure 10 (which shows the distribution of viewing time by files for the three operators combined), the four values on the left side change more rapidly than the four on the right without affecting the calculated correlation.

Assuming that random data variations are averaged out by combining the 57 presentations, bias in the operator's coverage of the display can be determined. It will be shown that the operator does not view the display uniformly. The number of presentations in which a domain is missed depends on the order of appearance and the location of the domain. The time spent viewing the display is not uniformly distributed across the display.

Horizontal Coverage

The analysis of horizontal coverage is based on the analysis of files (i.e., of columns of domains) and will consider (1) the number of missed domains in each file, (2) the total viewing time in each file during a presentation, and (3) the correlation between the number of missed domains and the total viewing time in the files.

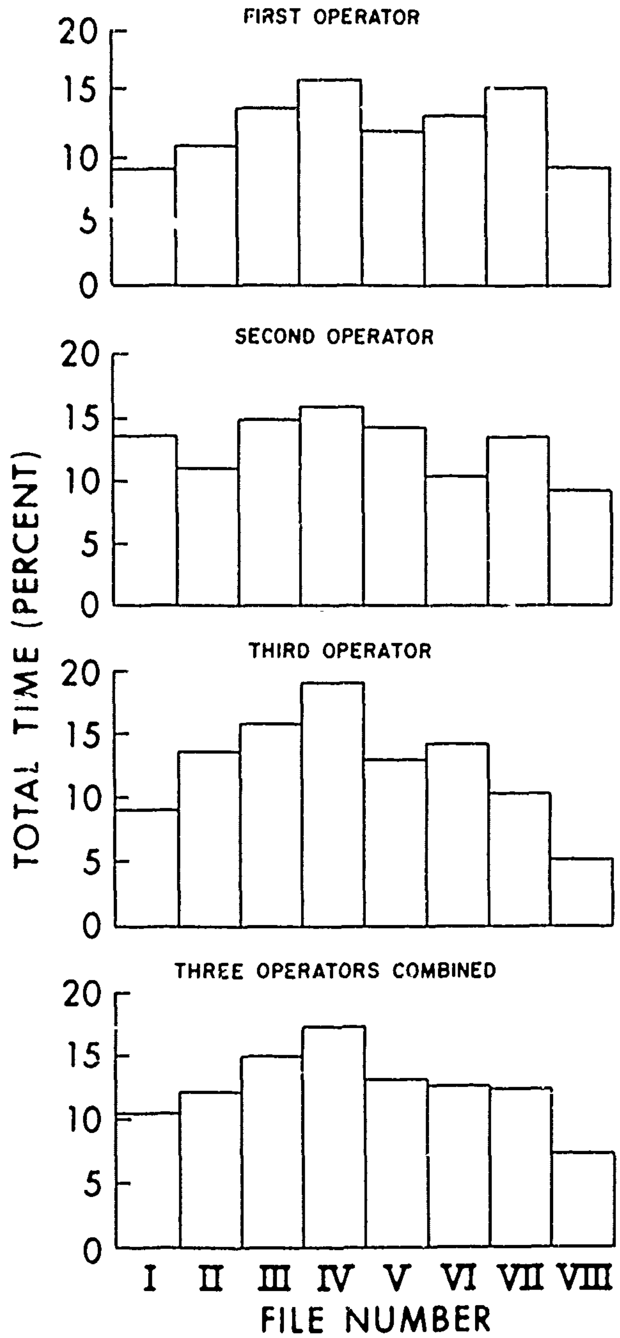

Figure 10. Distribution of Viewing Time for Each File on a Display

Distribution of Missed Domains. Table 2 shows the number of domains missed in each file by each operator, and the sum for the three. These data can be used to calculate the Spearman rank correlation[9] between the number of domains missed in a particular file and the distance of the file from the center of the display. For this correlation, files IV and V (nearest the center) are ranked 1, and files I and VIII (farthest from the center) are ranked 4. The correlation between the number of missed domains in a file and its distance from the center is shown in table 3. As table 3 shows, there is a high correlation between the number of missed domains in a file and the distance of the file from the center of the display. That is, domains in files to the left and right sides of the display are more likely to be missed than domains in files at the center.

Distribution of Viewing Time. Table 4 shows the relative viewing time of the files for each operator, as well as the relative viewing time of the three combined. The hypothesis that the relative viewing time in each file is a sample from a uniform distribution was tested using the Kolmogorov-Smirnov test.[9] The hypothesis was rejected at the 0.05 level for each operator alone and for the three combined — they did not distribute their time uniformly across the display.

Figure 10 shows the distribution of time by files for each operator and for the three combined. The figure shows that viewing time decreases for all three operators as the distance of the files from the center of the display increases. The correlation between relative viewing time and distance from the center for the three operators combined is -1.0, which is significant at the 0.01 level.

Correlation Between Viewing Time and Missed Domains. The Spearman rank correlation[9] between the number of missed domains and the viewing time (from tables 2 and 4, respectively) is shown in table 5. The number of missed domains and the viewing time in a file are related, as is indicated by the significant negative correlation between them for each operator and for the three combined. Files that had the most viewing time had the fewest missed domains and those that had the least amount of viewing time had the most.

Table 2. Number of Domains Missed in Each File

Operator	File Number							
	I	II	III	IV	V	VI	VII	VIII
1	24	9	5	2	5	5	12	24
2	32	25	13	14	12	21	20	34
3	42	25	20	23	26	28	28	45
Combined	98	59	38	39	43	54	60	103

Table 3. Correlation Between Number of Missed Domains in a File and Distance from Center

Operator	Correlation	Significance
1	.97	.01
2	.80	.02
3	.87	.01
Combined	.90	.01

Table 4. Relative Viewing Time in Each File

Operator	File Number							
	I	II	III	IV	V	VI	VII	VIII
1	.090	.109	.139	.162	.120	.133	.153	.091
2	.133	.107	.146	.154	.139	.100	.132	.089
3	.091	.138	.157	.190	.130	.141	.102	.051
Combined	.104	.122	.149	.171	.130	.125	.124	.073

Table 5. Correlation Between Number of Missed Domains and Viewing Time

Operator	Correlation	Significance
1	-.72	.05
2	-.74	.05
3	-.87	.01
Combined	-.95	.01

Effect of Target Location. The number of missed domains and the viewing times were not related to the actual locations of targets. Table 6 shows the number of actual targets by files for each operator. The correlation between target location and relative viewing time with the number of missed domains is shown in table 7. None of these correlations is significant at the 0.05 level; so it may be assumed that the actual locations of targets do not affect the parameters considered here for operator search.

The operators' coverage was not related to selected targets either, as the correlations presented in table 8 show. (Table 8 results from correlating the data in table 9 with those in tables 2 and 4.) Since none of the correlations in tables 7 and 8 is significant at the 0.05 level, it may be assumed that neither the viewing time nor the number of missed domains is related to target location.

Missed Domains and Order of Appearance

This analysis is based on the number of missed domains in bands across the display. The presentations analyzed had from 1 to 7 bands, depending on when the operator detected the target. The bands are numbered in order of their appearance on the display, and only complete bands are considered. The presentation shown in figure 9 has three complete bands; band 1 appears first and band 3 appears last. Thus, band 1 was on the display for the longest time and band 3 for the shortest. The data appearing at the top of the display are not included in the analysis.

Table 6. Number of Actual Targets in Each File

Operator	File Number							
	I	II	III	IV	V	VI	VII	VIII
1	1	1	3	1	5	5	4	1
2	3	4	3	6	2	1	4	3
3	2	4	1	2	4	3	7	2
Combined	6	9	7	9	11	9	15	6

Table 7. Correlation Between Number of Actual Targets and the Relative Viewing Times and Missed Domains in Bands

Operator	Viewing Times and Number of Targets	Missed Domains and Number of Targets
1	.32	-.36
2	.33	.05
3	-.23	.17
Combined	.43	-.31

Table 8. Correlation Between Number of Selected Targets and the Relative Viewing Times and Missed Domains in Bands

Operator	Viewing Times and Number of Targets Selected	Missed Domains and Number of Targets Selected
1	-.33	.17
2	.22	-.01
3	-.46	.39
Combined	-.45	.41

Table 9. Number of Selected Targets in Each File

Operator	File Number							
	I	II	III	IV	V	VI	VII	VIII
1	1	3	1	1	6	2	2	3
2	1	3	3	3	0	1	3	2
3	4	2	2	1	1	1	3	2
Combined	6	8	6	5	7	4	8	7

Table 10 shows the number of domains missed in each band by the three operators combined. The data are grouped according to the total number of bands on the display at the end of a presentation. The correlation between the number of missed domains in each band and the order of appearance of the band for each presentation length is shown in table 11. As table 11 shows, the number of missed domains in a band is highly correlated with the order in which the band appeared. Bands appearing first were on the display for the longest time and had the fewest missed domains. (Band 1 appeared first and was always on the display for the longest time.)

Discussion

The results obtained during this study are primarily for search. The parameters considered here are independent of the operator-selected target locations, and only the viewing time in a single column was correlated with the actual target column.

Table 10. Total Number of Domains Missed Within Each Band

Band Number	Number of Bands Presented						
	1	2	3	4	5	6	7
1	7	5	19	4	0	7	5
2	—	9	28	8	1	4	11
3	—	—	61	10	4	12	11
4	—	—	—	24	5	13	14
5	—	—	—	—	12	14	33
6	—	—	—	—	—	20	60
7	—	—	—	—	—	—	93

Table 11. Correlation Between the Order of Appearance of Bands and the Number of Missed Domains

Number of Bands Appearing	Correlation	Significance
2	1.0	.5
3	1.0	.17
4	1.0	.05
5	1.0	.01
6	.943	.01
7	.991	.01

Since the PPI study[1] indicates that operators fixate targets, the lack of correlation between viewing time and selected targets was a surprising result. However, visual examinations of the records for the period after the operator called "Stop" showed that the operators did a great deal of searching after they stopped the presentation. In addition, during the experimental session, it was often observed that the operator would delay selecting a target column with the cursor or else change his mind after indicating a selection. In every case, visual observation of the EOG record showed that the operators were actively searching during the selection portion of the presentation, even though they had indicated by their call that a target had been detected. The searching occurred even when the operator found a strong target early in the presentation and quickly selected his first choice column. An analysis of this viewing after the display was stopped should show a correlation between viewing time and the selected target column.

The hesitancy to select the target column and the very intense searching after stopping the presentation (which occurred during most presentations) indicate that the operators called a target when they thought one was present but had not actually decided where it was. Apparently, they were first detecting and then localizing the targets.

Visual Search Characteristics. The distribution of missed areas and apportionment of time on the display were considered separately. Areas of the display were considered to have been observed if viewed for more than 0.1 sec, areas viewed for times ranging from 0.1 sec to several seconds were considered the same. Thus, it is not necessary to assume a priori that the distribution of viewing time over the display and the distribution of missed areas are related. However, the percentage of time spent viewing an area and the number of misses in that area were significantly related.

Coverage of the display by the foveal vision of the three sonar operators was not uniform. During most presentations, there were areas that were not fixated (see figure 8 and appendix B). Since there was adequate time to view each area, neglect of certain areas must be considered characteristic of the visual coverage of the DIMUS display. The locations of the unfixated areas for the three operators shows a tendency to miss data in the same areas. The missed areas were found to correlate significantly with the following factors:

- The order of appearance — areas in which data appeared at the end of a presentation were more likely to have been missed than those in which data appeared at the beginning.
- The horizontal distance from the center of the display — areas at the left and right sides of the display were more likely to have been missed than those at the center.

The relatively large number of missed areas at the top of the display (i.e., those that appeared at the end of the presentation) indicates that the operators were eliminating areas from consideration early in the presentations. As an example, consider the coverage shown in figure 8 and the unfixated area at the upper right-hand side of the display. The lack of coverage indicates that the operators concluded that the area did not contain a target; this decision (whether voluntary or involuntary) must have been based on data appearing early in the presentation. The time spent viewing different areas of the display varied extremely. During most presentations, some areas were fixated for relatively long periods of the available time and others for short periods or not at all.

The correlation between missed areas and distance from the center of the display cannot be attributed to the effect of target location. Table 2 shows that for the three individual operators, there were always at least two files with the same number or fewer targets than in the left and right sides (files I and VIII). Even so, the correlation between missed files and distance from the center was high for each operator and for the three operators combined. The location of the file with the most targets has no apparent effect either. Operator 3 had the most targets appearing in file VII, yet the correlation is between that of operators 1 and 2 for whom the most targets appeared in a more centrally located file.

The nonuniform distribution of viewing time is apparent from the percentage of time spent in the files on the display. As shown in figure 10, the amount of time the operators spent viewing centrally located areas was greater than that spent on the left or right sides of the display. Viewing time tended to decrease as the distance of the area from the center of the display increased. This nonuniform coverage cannot be attributed to the display presentation; there are no horizontal time variations on the display; all such variations occurred in the presentation of vertical data.

The nonuniform coverage observed here resulted from the search characteristics of the operators. Considering the large number of presentations that were combined in the analysis, variations caused by differences in the display data on individual presentations would have averaged out. Although the operators, individually and combined, visually covered the format in a nonuniform manner, the format did not dictate the search methods they used. They could easily have fixated all areas on the display and would still have been able to spend the most time on the center; or they could have divided their time equally across the display, without fixating areas at the top; or could have divided their time uniformly across the display, missing areas randomly.

The nonuniform visual coverage of the DIMUS display is consistent with the result of a study by Ford, White, and Lichtenstein,[5] who reported on subjects assigned to find a single black point appearing in a white background. White and Ford[6] observed nonuniform search on a simulated radar display, and it has also been observed for sonar operators searching a simulated PPI display.[1]

OPERATOR VISUAL COVERAGE AS A FUNCTION OF DISPLAY MARKING

The relation between the amount of time spent viewing an area of the display and the information on the display in that area will be considered in this section. As stated in the Introduction, the amount of time an operator views an area is assumed to be related to the relative importance of that area for detecting the target. The purpose of this section is to relate the visual search of the sonar operators to characteristics of the data on the display.

Effect of Selected Parameters

Since a target column was defined to be the column with the most marks in it, the visual search should be concentrated in areas of the display having the most marks. However, a study of sonar operator detection performance on the DIMUS display indicates that the mark frequency is not used exclusively for target detection.[10] In that study, it was found that the target columns selected by the operators were related to the following measures:

- Mark Frequency (MRKF) — The number of marks appearing in a column divided by the possible number of marks (the number of rows that appeared).
- Mark Run Length (MRL) — The mean number of continuous marks that appeared in a column.
- Blank Run Length (BRL) — The mean number of continuous blanks that appeared in a column.

To determine if these parameters affect the visual search in this study, each parameter was tested for a significant correlation with the operator viewing time. Appendix D gives the display statistics for each of these parameters by files as they were used for the following analysis.

Mark Frequency. If the operator selected target columns on the basis of mark frequency, then, on each presentation, the most time should have been spent in viewing areas of the display in which the column with the greatest mark frequency (GMRKF) occurred. To test this, an analysis was made using the same 6-column-wide areas (files) used previously, as shown in figure 9. To make the analysis, two files were selected from each presentation: the file with the greatest viewing time, and the file with the greatest mark frequency (GMRKF). The Spearman rank correlation was then calculated for the number of occurrences of the maximum viewing time in each file (table D-1) and the number of occurrences of the GMRKF in the file (table D-2). A correlation of 0.659 (significant at the 0.05 level) was found between the number of files with GMRKF and the number of files with the greatest viewing time.

Mark Run Length. The Spearman rank correlation was then calculated as above using the number of occurrences of maximum viewing time in a file (table D-1) and the number of occurrences of the greatest mark run length (table D-3). No such correlation was found.

Blank Run Length. Next, the blank run length was considered. A negative correlation was expected between the time spent in a file and the greatest blank run length (GBRL). The Spearman rank correlation was again calculated as above using the number of occurrences of maximum viewing time (table D-1) and the number of occurrences of the greatest blank run length (table D-4). Again, no correlation was found.

Since the operator can search for different clues during the course of a presentation, the viewing time and display data were also considered for areas smaller than a file. the 6-column by 12-row areas (domains) used previously (figure 9). The Spearman rank correlation between the relative amount of time and the relative value of a parameter in each domain was calculated for each presentation. The time spent in viewing each of these domains of the display was found to be significantly correlated with three parameters of the data on the display. However, the parameter-time correlation varied from presentation to presentation, with no correlation on some presentations. The number of presentations having significant Spearman rank correlations (0.05 significance level) and the parameters are as follows:

- 12 presentations: amount of time viewing each domain and the total number of marks in the domain.
- 17 presentations amount of time viewing each domain and the largest number of marks for a column within the domain.
- 16 presentations, amount of time viewing each domain and the largest number of continuous marks for a column within the domain.

No significant correlation was found for 30 of the 57 presentations considered.

Effect of Multiple Columns

Since the foveal vision covers an angle of 2 deg, more than one column of the display is actually viewed through the fovea at each fixation. In addition, the nonfoveal human vision covers a very wide angle, but with decreasing resolution away from the fixation point. Thus, the operator may consider several columns as viewed in a single fixation.

The maximum viewing time in an area was previously found to be related to the MRKF in the area, and since fixations cover more than one column, the time spent viewing an area is likely to be related to the combined MRKF for several columns. Therefore, it was assumed that the total time viewing a group of 3 columns (for example) would be correlated with the number of marks in the 3 columns. To determine this correlation, the number of marks in each group of three adjacent columns was determined for each presentation. The groups were then ranked on the basis of the number of marks that appeared on the display; the group with fewest marks was ranked 1, next fewer marks, 2, etc. The percentage of the total time in the presentation that was spent in viewing each group was then determined. This was done for each presentation, and from these data, the linear (Pearson product) correlation of the relative amount of time with the relative number of marks was found.

The linear correlation and its 95-percent confidence interval are given in figure 11 for the proportion of time spent viewing each group of adjacent columns for groups ranging from 1 to 20. Significant correlation was found for all but the 1-column grouping. The correlation increases with the number of columns averaged until 7 columns have been combined. Groupings larger than 7 have about the same correlation (0.8) until 19 columns are included. At this grouping, the correlations start decreasing with larger combinations.

Comparison of figures 11 and 12 (visual angle versus number of columns) indicates that the correlation in figure 11 increases until the number of columns averaged corresponds to a visual angle of approximately 4 deg. The correlation then stays at about the same value until almost 9 deg is included. Averaging over larger visual angles causes a decrease in the correlation.

Since the percentage of total time viewing a group of columns is highly correlated with the relative number of marks in the group, the linear regression was determined for each grouping of columns. Figure 13 is an example using groups of 8 columns (the same 8-column groups in figure 10) — it shows the regression line along with the relative viewing time for each ranking of the 8-column groups. In this figure, the relative amount of viewing time in a group of columns increases with the relative increase in mark density. This figure is representative of the regressions obtained for all the groupings shown in figure 10.

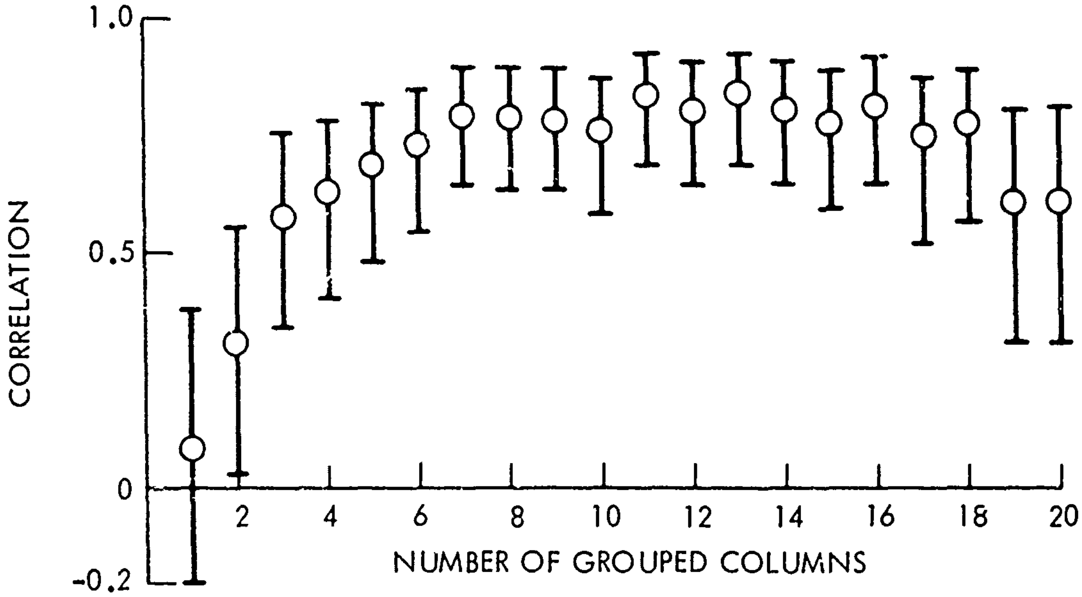

Figure 11. Linear Correlation Between Time Viewing Columns and the Relative Number of Marks in the Columns

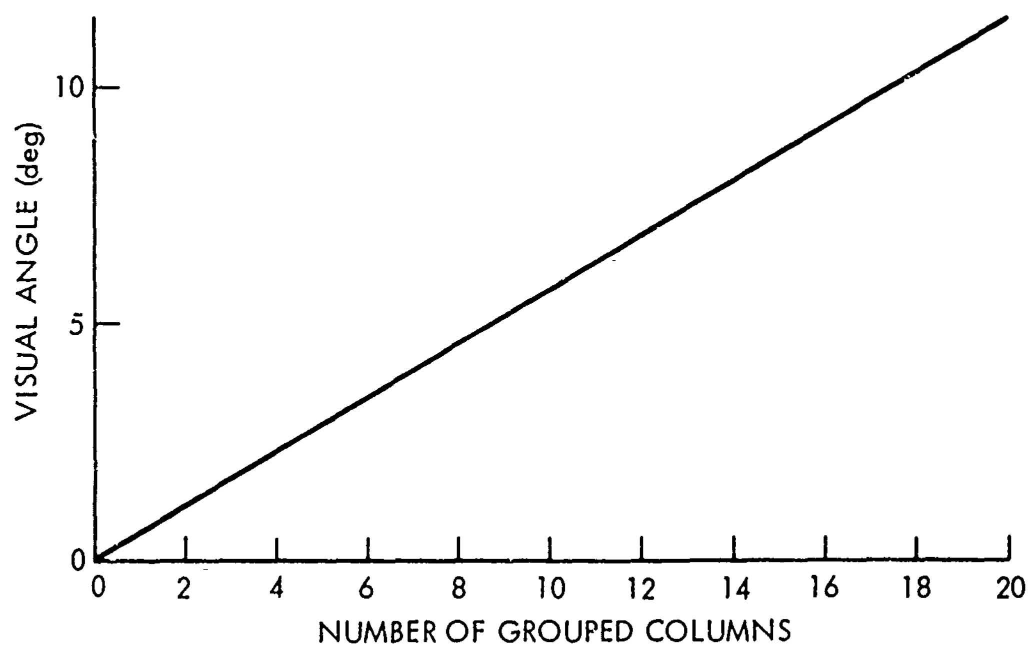

Figure 12. Visual Angle Subtended by Groups of Columns

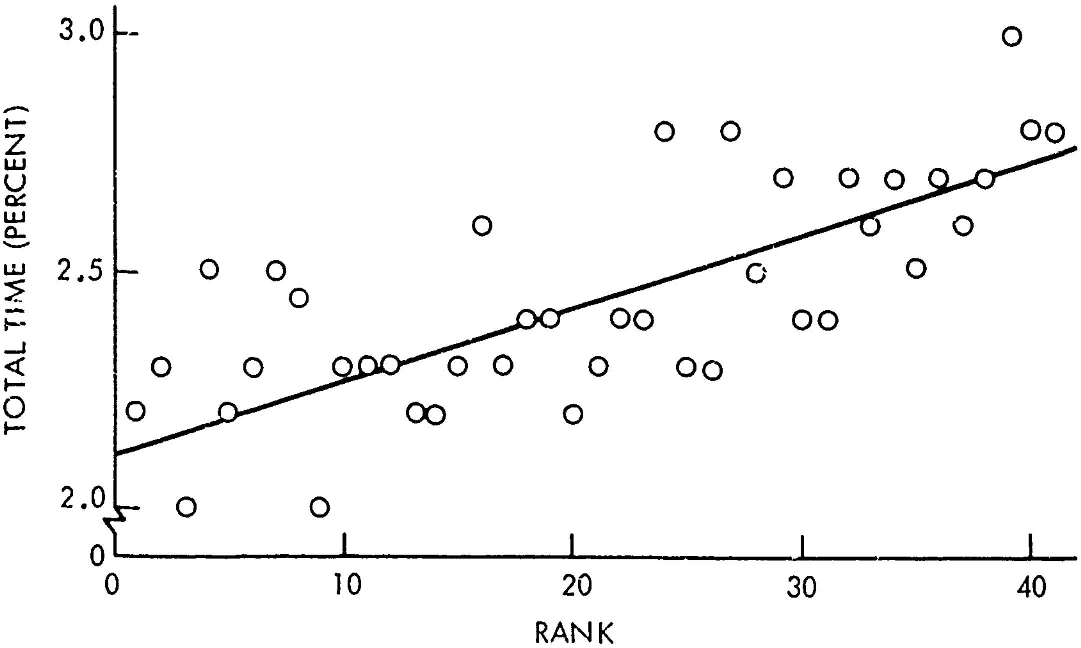

Figure 13. Percent of Total Time Spent at Each Ranking

Discussion

Correlation between the greatest mark frequency and time spent viewing an area shows that operator attention was concentrated on groups of columns on the basis of mark frequency. During the display presentation, while the operator was searching to decide if a target was present, he was using the correct measure, mark density. However, even though he had stopped the display, the operator could continue his visual search before selecting the target column. This visual search was not analyzed, and probably is related to factors other than GMRKF.

Attempts to identify important parameters other than mark density on the basis of viewing time as the display developed led to ambiguous results. Consideration of the domains for each presentation was expected to identify parameters that drew the operators' visual attention to local area. Each of these second-order parameters considered (as listed on page 29) was significantly related to the viewing time on some but not all presentations. In addition, there was overlap, since significant correlation was found for more than one clue on the same run. The lack of correlation for any of the three clues on over half the runs is probably caused by the operator's inconsistency in using these clues, and possibly from the use of other clues not considered here. Thus, it is concluded that the operator uses clues other than mark density, but these clues are not used consistently, varying between runs and often during runs.

The most important factor determining the operator apportionment of his viewing time is the average mark frequency over several columns. For each operator, the time spent viewing a multiple-column area has a significant positive correlation with the relative mark density in the area. Only for the case of a single column was there no significant linear correlation between time spent viewing the column and the relative mark frequency in the column.

GENERAL DISCUSSION

Search Procedure on the DIMUS Display

On the basis of the information in the preceding sections, the operator search procedure is apparent for the display used in this study. When the presentation starts and only a few lines are on the display, the operator looks back and forth at all areas of the display. After several lines have appeared, and while the presentation continues to develop, the operator's attention is drawn more to areas in which relatively large numbers of marks appear. The operator also looks for other clues that may help him to decide on the target column (such as a relatively large number of connected marks). Then, after some areas of the display are eliminated from consideration, a few columns are looked down to decide if a target is present. When the operator decides a target is present, he stops the display presentation. Finally, unless the target is particularly clear, he looks quickly at all the possible target columns to select the one he will call.

Superimposed on the search pattern are certain tendencies of the operator in viewing the display. Some areas of the display receive more visual attention than others. The operator tends to center his vision in the horizontal direction. The operator keeps referring back to the oldest data and spends the most time in looking at that data.

The data most likely to be missed are those at the sides, and those that appear last in the presentation. Thus, the display should be designed so that (1) the most likely or most important target areas are centered, and (2) the most significant data appear first.

Visual Angle for Search

The visual angle used by the sonar operators for viewing the display is between 4 and 5 deg. There are three independent results that indicate the value of angle used for search: (1) The absence of vertical moves until the display had expanded to 4 deg in the operator's vision indicates that they were using this angle for viewing; (2) the correlation of time with average mark density for multiple columns indicates the operator is viewing data at an angle greater than 4 deg; and (3) the first eye movements in the PPI study did not occur until the circle had grown to subtend approximately 5 deg of visual angle. Thus, indication is strong that the viewing angle used by sonar operators for search is from 4 to 5 deg.

An angle of viewing subtending more than 2 deg indicates that the operators are not relying on the foveal vision alone for searching the display. It may be that the operator is keying the angle of view he uses to the resolution required for the display, but it is unlikely. The density of the data on the PPI display[1] was quite different from that on the DIMUS display, yet the visual angle used for search was approximately the same for both displays.

Since the visual coverage used by the operator is greater than 4 deg, the nonuniform viewing time shown in figure 10 should be reconsidered to see if the results change. The time spent viewing areas for figure 10 was based on a fixation point, not a fixation area. The viewing time was recalculated using an angle of ± 2.8 deg around a fixation point; 2.8 deg corresponds to 9 grouped columns in figure 11 and was chosen because the correlation versus number of columns is almost constant. The same nonuniform coverage of figure 10 is also shown in figure 14. In addition, recalculation of the correlation between the time and missed areas (page 20) using this ± 2.8-deg visual coverage gives the same conclusions as using fixation points.

Since the visual angle used by trained sonar operators is greater than 4 deg, the search is made with both foveal and nonfoveal vision. The nonfoveal vision has less resolution than the foveal vision and the color perception is different in the two areas, with color confusion occurring in some locations. Variation in color perception between the foveal and the nonfoveal vision would have an effect on a color-coded DIMUS-type display, indicating that for a color-coded display, the colors chosen should be matched with the color detection characteristics of both the foveal and the nonfoveal vision. However, this would have no effect on a DIMUS display using brightness only for intensity coding.

CONCLUSIONS AND IMPLICATIONS

CONCLUSIONS

The visual search used by sonar operators on a DIMUS display has the following characteristics:

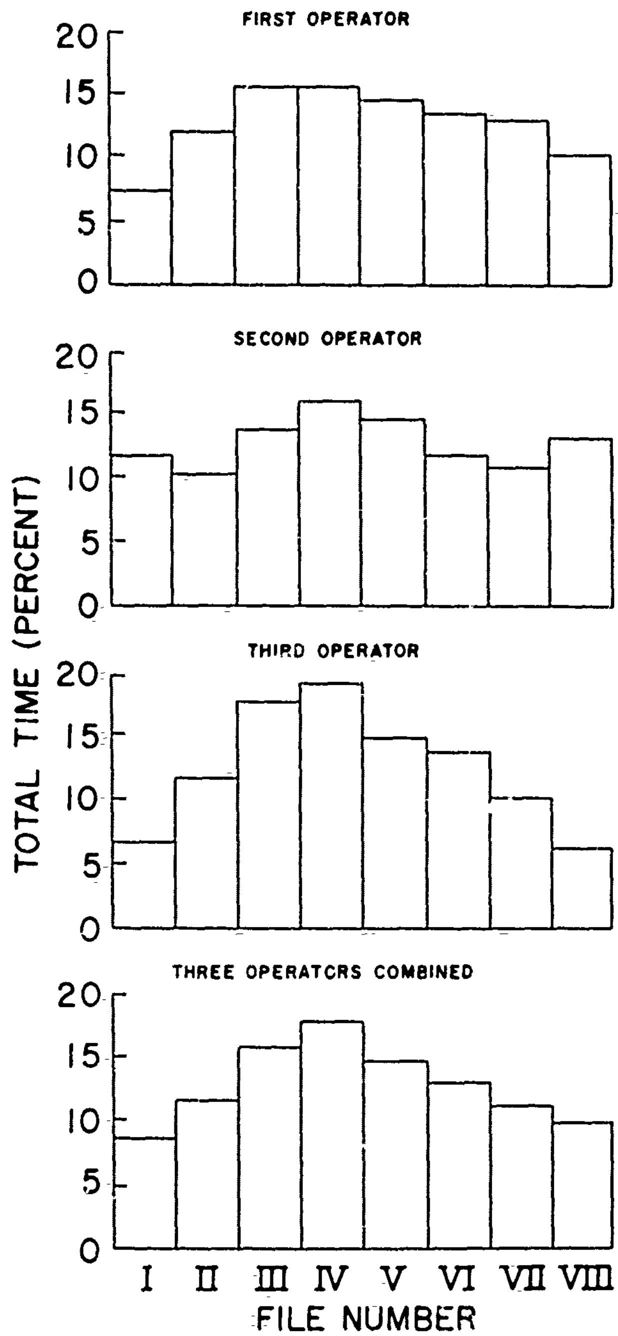

Figure 14. Distribution of Viewing Time for Each File on the Display Using 5.6-deg Angle of Visual Coverage

- The amount of time spent searching decreases with the horizontal distance from the center of the display.

- The time spent viewing an area is proportional to the time the area has display data.

- Nonfoveal vision is used in search — the visual angle used for searching subtends from 4 to 5 deg.

- The average fixation time is 0.23 sec (0.36-sec standard deviation).

- The most time spent looking at the display is in fixations ranging from 0.2 to 0.4 sec long.

- The mean eye movement is 4.14 deg (4.15-deg standard deviation) for a display subtending 23.5 by 28 deg.

- The length of eye movements may be related to the visual angle subtended by the display.

Conclusions reached in evaluating the sonar operator's visual search of the display are

- The operator's coverage is not complete, since some areas of the display are not even fixated.

- The time spent viewing the display is not uniformly distributed horizontally.

- The time spent viewing the display is not uniformly distributed vertically.

The visual sampling of the DIMUS display is related to the data presented in the following ways:

- Operators are not consistent in the measure used on the display data: The time spent viewing an area of the display may be correlated with the number of marks in the area, the line with the most marks in the area, or the line with the most continuous marks in the area.

- The time spent viewing a group of columns is related to the combined mark frequency in the columns.

IMPLICATIONS

Implications of this study for display design for sonar operators are

- Nonfoveal as well as foveal vision is used in search; thus, the display must be designed so that it can be seen effectively with both types of vision.

- Concentration of operator attention to the center of the display and on the oldest data displayed indicate that target detection performance will vary with target location on the display. When possible, the display should be formated so that the most important data appear first and are centered on the display.

- Operator search on a display is governed by several properties of the data displayed. The search is not determined solely by target-indicating parameters on the display — visual attention may be drawn to an area by data properties that do not actually aid in target detection. Thus, the most important parameters determing the visual search should be most highly correlated with target detection.

Implications of this study for sonar operator training are

- Operators should be trained to concentrate search in the most likely target areas, or, if targets can appear anywhere with equal probability, to search the display uniformly.

- Operators should be trained to ignore characteristics of displayed data that do not help to indicate targets.

- Possible improvement in target detection by training in the use of nonfoveal vision should be examined.

- Possible relation between training and proficiency level with visual search angle should be examined.

REFERENCES

1. R. L. Mason, Visual Sampling on a Simulated PPI Display, NUSC Technical Report 4201, 30 November 1971.

2. Dunlap and associates, A Study of the Visual Search Behavior of Sonar Operators, report prepared for the Bureau of Naval Personnel, BSD 68-447, 26 January 1968.

3. A. L. Yarbus, Eye Movements and Vision, Plenum Press, New York, 1967.

4. R. L. Mason, "An Automatic Zeroing Circuit," accepted for publication in IEEE Transactions on Bio-Medical Engineering.

5. A. Ford, C. T. White, and M. Lichtenstein, "Analysis of Eye Movements During Free Search," Journal of the Optical Society of America, vol. 49, no. 3, March 1959, pp. 287-292.

6. C. T. White and A. Ford, "Eye Movements During Simulated Radar Search," Journal of the Optical Society of America, vol. 50, no. 9, September 1960, pp. 909-913.

7. J. M. Enoch, "Effect of the Size of a Complex Display on Visual Search," Journal of the Optical Society of America, vol. 49, no. 3, March 1959, pp. 280-286.

8. R. L. Mason, FORTRAN Programs for Non-Parametric Statistics," NUSC Technical Report 4597, 5 October 1973.

9. S. Siegel, Non-Parametric Statistics for the Behavioral Sciences, McGraw-Hill Book Co., Inc., New York, 1956.

10. J. C. Lamb, J. M. DiJoseph, and F. M. Ball, "Analysis of Detection Performance on a DIMUS-Type Display," Perception and Psychophysics, in preparation.

Appendix A

OPERATOR INSTRUCTIONS

In this experiment, you will be observing simulated sonar displays and deciding whether or not a target is present in the display.

First, I will describe how a sonar display is generated. Imagine a submarine with a series of listening devices called hydrophones spaced around it. These hydrophones are like microphones in that they pick up mechanical activity and transform it to electrical impulses. Each line on the display represents one sweep of 48 hydrophones. Only those impulses above a certain strength will show up as a mark in the display; if below, no point will show up. The presence or absence of a point indicates only that the signal was above or below a certain voltage level and does not indicate degree, that is, how much above or below.

Every second we take another sweep of the hydrophones. That is to say, we listen from each of the hydrophones and read 1 line, 48 columns in length, on the display.

You must realize that the hydrophones are picking up both random noise and what would be the noise from a target and cannot discriminate between them. The discrimination is your task. The only difference between target and noise is that the probability of displaying a point is greater for a target. This, however, does not imply that a target impulse must be present on every bearing sweep, but that the probability of a target point appearing is greater.

Generally, we can say that if a target is present, its path will be indicated on the display by a greater frequency of points in one given column than those columns in which only noise is present. To give you a better idea of what we mean by this, we have a sample display.

(Show sample display.)

Sometimes a target is present — (show target).

At other times it is not — (take target off).

For these conditions that you will be observing, your task is to first decide whether or not a target is present and then, if one is, to indicate its location as I move the target path indicator across the columns — (demonstrate cursor).

There are certain specifications for the displays you will be observing:

1. The target, if present, will be there from the beginning of the display.

2. If a target is present, it will always appear in one column; that is, it will not change bearing.

Responses: The first thing you do when you are quite sure you have a target is call out "Stop," and I will stop the continuation of the display. I will then slide the target path indicator or cursor over the columns. When the cursor is on the column in which you saw the target, say "Stop" again. You may choose up to 3 targets, indicating the strongest target you see first, the next strongest target second, and the weakest target last. If you have not yet decided whether a target is present or not after the completion of the display, you will have approximately 30 sec more in which to decide. You may call out "Stop" at any time during those 30 sec, and, if you have spotted one or more targets, I will move the cursor until it is over the target or targets you have chosen.

The electrodes we have placed around your eyes are connected to this machine over here and will tell us where you are looking as the display falls down the screen. The noises you may hear from the setup over there have nothing to do with the connection between you and the machine; so do not be distressed when you hear them. There is no shock involved at all.

In order to calibrate the equipment, we will begin the session by presenting a series of spots on the screen. We would like you to look directly at each spot as it appears and for as long as it is present on the screen. At the beginning of each trial and immediately after, you call out "Stop" when you have made your decision about the presence or absence of a target, one spot will again appear on the screen, and you will look directly at that spot when it is present. In other words, whenever a spot is present on the screen, look directly at it for as long as it is there.

Questions?

Please sit quietly and keep your movements to a minimum during each presentation. When the spot that comes on after you have made your decision disappears, feel free to relax and sit back in the chair until the next presentation begins.

Appendix B

VISUAL COVERAGE OF EACH PRESENTATION

The shaded areas in figures B-1 through B-3 represent domains that were fixated a total of 0.1 sec or more during a presentation.

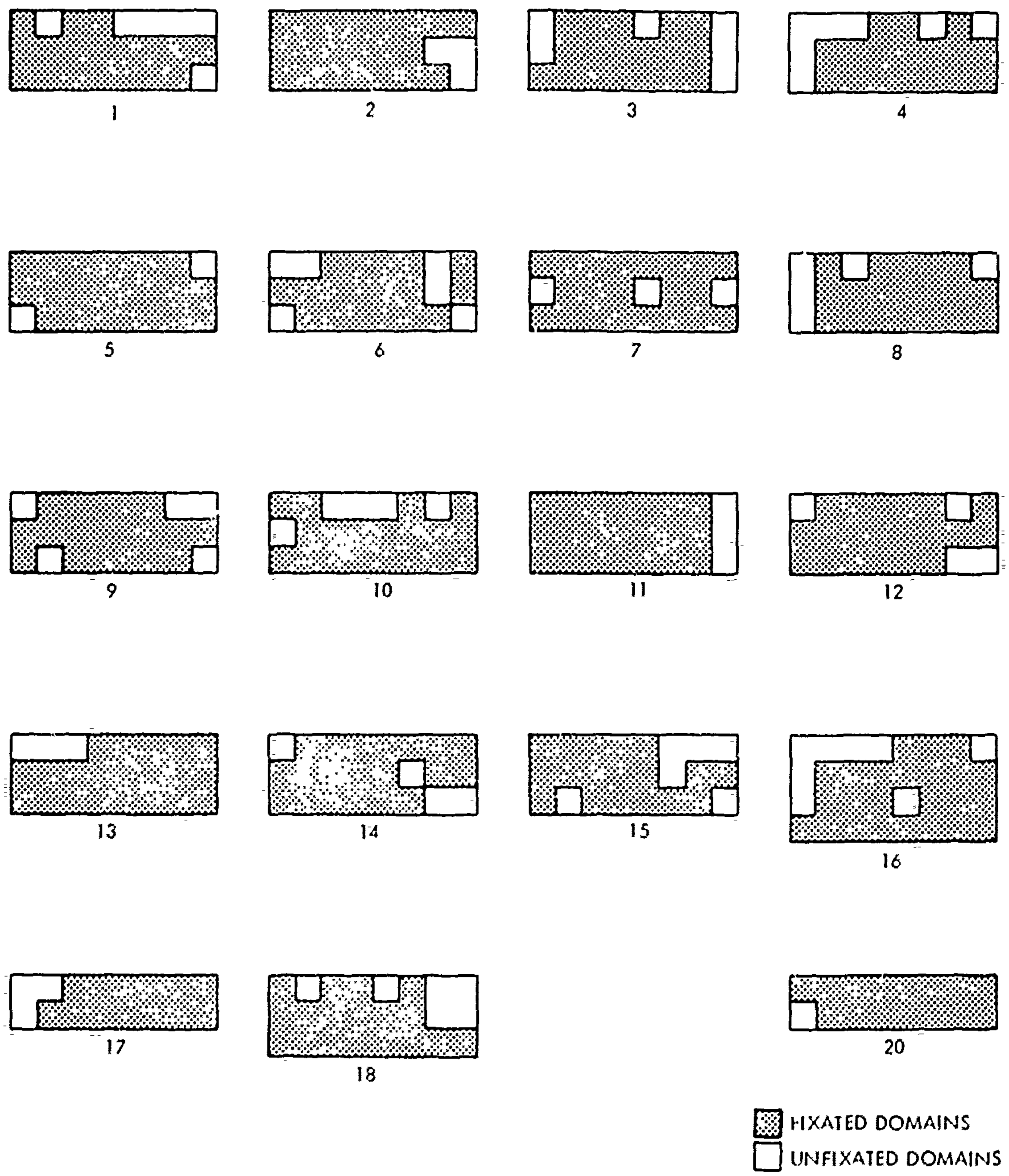

Figure B-1. Domains Fixated by Operator 1

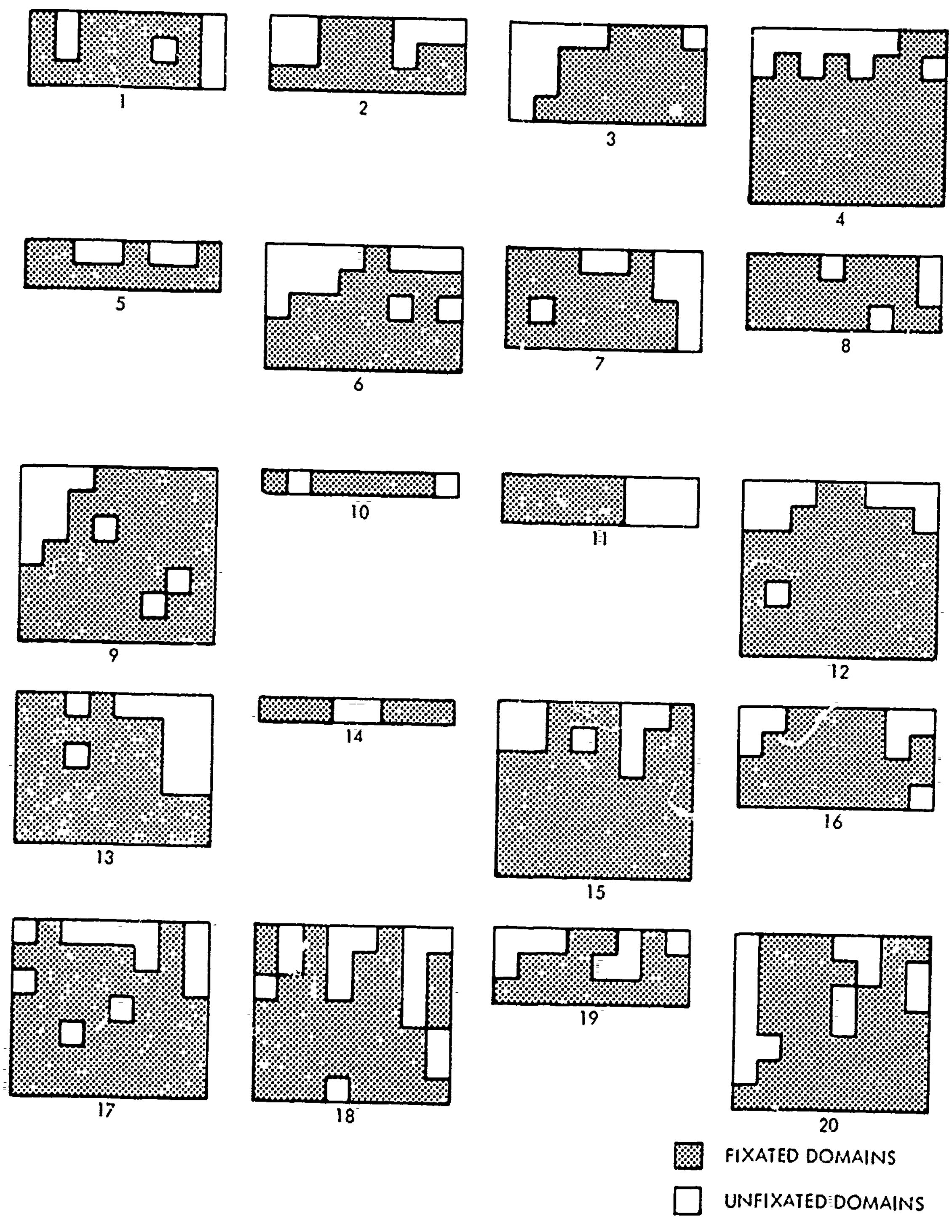

Figure B-2. Domains Fixated by Operator 2

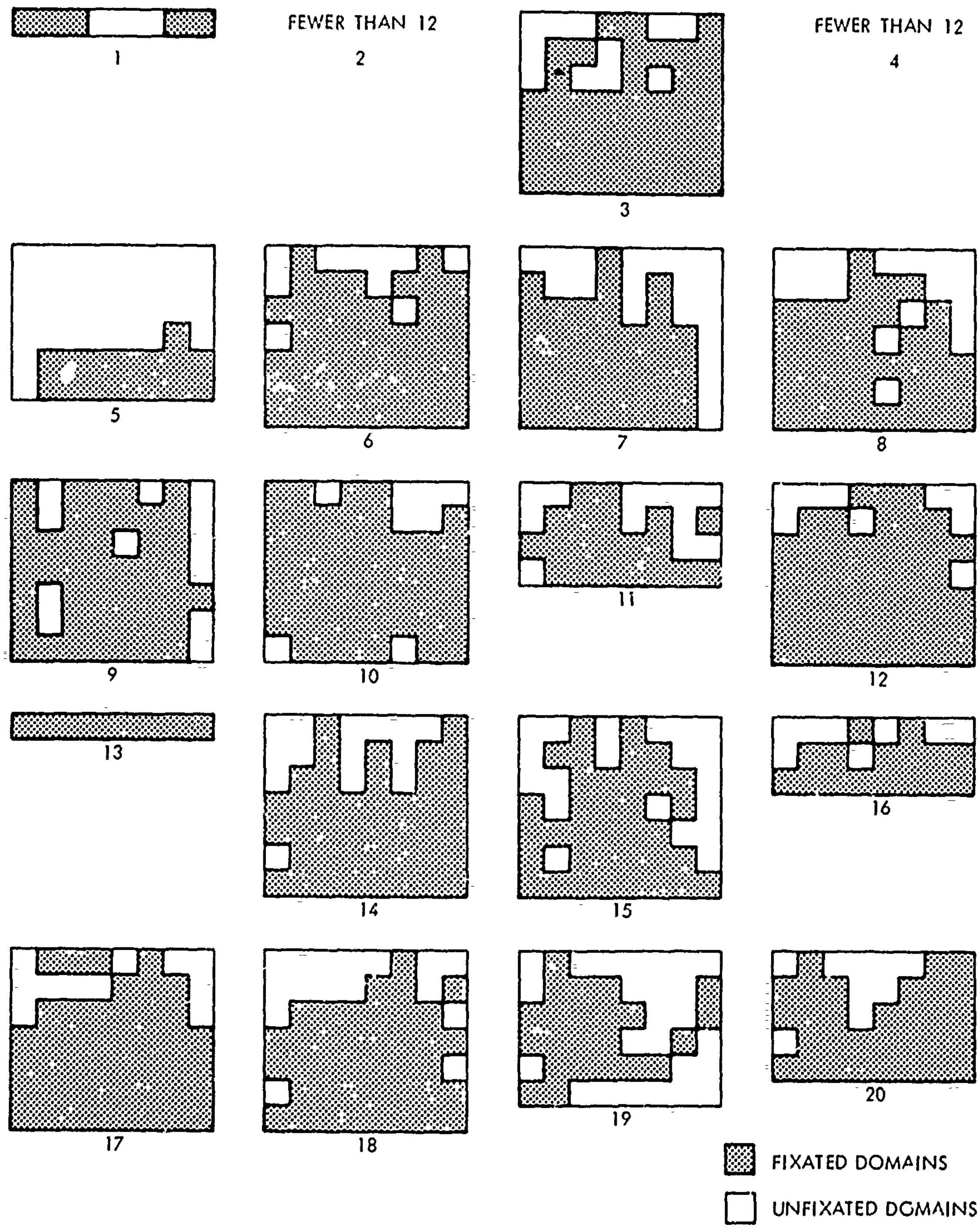

Figure B-3. Domains Fixated by Operator 3

Appendix C

MISSED DOMAINS

The following table gives the number of presentations in which each 6-column by 12-row area on the display was not fixated by the three operators. This table, in effect, gives the distribution of unfixated areas for the different length presentations. Table C-1, part 1, gives the number of missed areas for the 18 presentations that went 84 or 85 rows before being stopped. Part 2 gives the missed areas for the presentations that were stopped with 72 to 83 rows appearing on the display, etc.

Table C-1. Number of Presentations in Which Each Domain of the Display Was Not Fixated (Three Subjects Combined)

		File I	File II	File III	File IV	File V	File VI	File VII	File VIII	No. of Runs
	Columns	1-6	7-12	13-18	19-24	25-30	31-36	37-42	43-48	
Rows										
1.	1-12	1	0	0	1	0	1	0	2	
	13-24	3	2	0	0	1	1	0	4	
	25-36	1	3	1	0	0	0	2	4	
	37-48	3	1	0	0	3	1	1	5	
	49-60	9	2	1	4	3	4	2	8	
	61-72	13	10	5	8	3	5	6	10	
	73-84	15	13	11	7	10	13	12	12	18
2.	1-12	1	0	1	1	1	1	1	1	
	13-24	2	0	0	0	0	0	1	1	
	25-36	1	1	1	1	2	2	1	3	
	37-48	1	1	2	1	1	2	3	2	
	49-60	2	1	1	1	2	2	3	2	
	61-72	2	1	3	2	3	3	3	3	3
3.	1-12	0	0	0	0	0	0	0	0	
	13-24	1	0	0	0	0	0	0	0	
	25-36	1	0	0	1	0	1	0	1	
	37-48	1	1	1	1	1	0	0	0	
	49-60	2	1	2	2	1	2	1	1	2
4.	1-12	2	0	0	0	0	0	0	2	
	13-24	2	2	0	0	1	0	1	2	
	25-36	4	4	1	0	0	1	0	1	
	37-48	4	4	2	3	2	1	3	5	5
5.	1-12	4	2	0	0	0	1	2	10	
	13-24	8	2	0	1	2	5	3	7	
	25-36	12	9	6	2	4	5	9	14	21
6.	1-12	2	0	0	0	0	1	1	1	
	13-24	1	1	1	1	0	2	2	1	4
7.	1-12	0	1	0	2	2	1	0	1	4

Appendix D

DISPLAY STATISTICS BY FILES

The following tables give the number of presentations for which the maximum of a selected parameter occurred in each file on the display. Table D-1 shows the number of presentations in which an operator's greatest viewing time occurred in each file (e.g., operator 1 had a maximum viewing time in file III on two presentations). Tables D-2 through D-4 give display statistics; table D-2 shows the number of presentations for which the column with the greatest mark frequency (GMRKF) occurred in each file. Table D-3 shows the number of presentations for which the column with the greatest mark run length (GMRL) occurred in each file. Table D-4 shows the number of presentations for which the column with the greatest blank run length (GBRL) occurred in each file.

When ties occurred on a presentation, each file with a maximum was counted. Thus, the total for any subject may be greater than the actual number of presentations.

Table D-1. Number of Occurrences of Greatest Viewing Time in Each Location

Operator	File							
	I	II	III	IV	V	VI	VII	VIII
I	1	1	2	4	0	3	5	3
II	2	3	3	5	3	0	2	2
III	2	2	1	4	3	6	1	0
Combined	5	6	6	13	6	9	8	5

Table D-2. Number of Occurrences of GMRKF in Each Location

I	1	1	3	1	5	5	4	1
II	3	4	3	6	2	1	4	3
III	2	4	1	2	4	3	7	2
Totals	6	9	7	9	11	9	15	6

Table D-3. Number of Occurrences of GMRL in Each Location

I	0	1	3	1	2	4	3	5
II	1	3	4	5	2	1	4	2
III	2	2	1	1	4	1	7	3
Totals	3	6	8	7	8	6	14	10

Table D-4. Number of Occurrences of GBRL in Each Location

I	3	1	2	2	3	4	1	3
II	4	2	4	3	1	0	5	2
III	5	2	2	3	1	3	9	0
Totals	12	5	8	8	5	7	15	5