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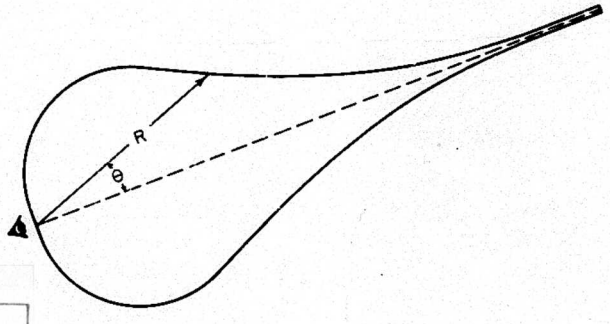

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Edited by
Ailene Morris and E. Porter Horne

Armed Forces—NRC Committee on Vision

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Publication 712

Visual Search Techniques

Proceedings of a Symposium

Sponsored by the

ARMED FORCES—NRC COMMITTEE ON VISION

Held in the

Smithsonian Auditorium, Washington, D. C.

April 7 and 8, 1959

Edited by

AILENE MORRIS AND E. PORTER HORNE

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PREFACE

For a second time, the Armed Forces — NRC Committee on Vision scheduled a vision research symposium as the principal event of its annual meeting. The dates were 7 and 8 April 1959, and the place was the Smithsonian Auditorium, where a successful annual meeting had been held in 1958. The symposium for the 1959 meeting dealt with Visual Search Techniques; this timely subject was examined in considerable detail during the two days of sessions, as a perusal of this Proceedings volume will show. The total attendance was slightly over two hundred, and a high level of interest was maintained during the entire meeting.

Major credit for organizing the symposium on visual search techniques is due Dr. Ailene Morris of the U. S. Navy Electronics Laboratory. As a representative of the program committee appointed by the Chairman of the Committee on Vision, she carried out most of the detailed work on setting up the program and inviting the speakers. Discussants for the several sessions were selected in advance, and were sent texts of the papers to be presented in the appropriate sessions. Although complete success was not achieved in obtaining pre-symposium copies of the manuscripts, still the batting average was high enough that this technique proved its worth without question. In addition, of course, there was open discussion from the floor, and it was recorded and is presented in these proceedings to the maximum degree possible under the circumstances.

My colleague in the Vision Committee Secretariat, Dr. E. Porter Horne, has performed the onerous task of editing the twenty-three manuscripts and the discussion items and preparing them for the publisher and the printer. Thus he too deserves a vote of thanks from all those who will profit by reading the following pages.

Stanley S. Ballard, *Executive Secretary*
Armed Forces — NRC Committee on Vision

FOREWORD

Visual search continues to be an important tool of the Armed Forces in the avoidance of mid-air collisions, in air-sea rescue, in missile detection and guidance, and for general reconnaissance, surveillance, and lookout. Despite the advances made since World War II in the development of electronic and acoustical methods of target detection, visual performance still plays a vital role in search operations. Field observations have revealed, however, that the patterns and procedures followed in visual search for whatever purpose vary markedly without demonstrable or observable causes for variation. Moreover, visual search techniques are never precisely described by participants and are seldom analyzed or evaluated.

As the use of visual search has continued, so has the need for the development of optimal search techniques. The best attack on the problem of deriving optimal procedures for visual search operations appeared to be a broad examination of present techniques and operational data together with a synthesis of the findings of research in independent but related areas. Operations analysis, detection theory, visual psychophysics, and atmospheric optics were considered to be among the areas of possible contribution to the development of a theory of successful visual search calculations and of experimental verification.

Accordingly, specific action was initiated in the summer of 1958 to bring together both operational and research people in a symposium on visual search techniques for the purpose of examining operational practices and visual research data in order to develop optimal techniques and procedures. The Armed Forces — NRC Committee on Vision and the U. S. Navy Electronics Laboratory offered their sponsorship and support for the symposium. Announcements of the proposed meeting were sent to the members of the Vision Committee, to military agencies known to be dealing with search problems, and to persons who had published articles concerned with or related to visual search. Suggestions for program topics and for individual papers were solicited. After it became apparent that many people were interested in attending, the decision was made to hold the meeting in Washington in April 1959.

In an early planning session, Dr. Robert M. Boynton, of the University of Rochester, aptly commented that we are now in the days of phenomenal advances in electronic sensors. Every day, it seems, we hear of further progress and refinements; equipment is becoming more compact, more versatile. However, as he went on, ". . . we must admit one thing — no one is ever going to re-design the human eye, so all we can do is determine its capabilities and learn to use it more effectively." In approaching this objective, the planning committee organized the program along functional lines: how we presently use the eye in operational situations, how we might use the eye for highest detection probability, how sensitive the eye is to begin with, and how it performs in a controlled search problem.

The meeting began with an invited lecture, "Operational Background and Physical Considerations Relative to Visual Search Problems," by Dr. E. S. Lamar. In the first session, representatives of the Armed Forces presented statements of existing doctrine and of operational needs and described measures that have been taken in practical situations to meet these needs. The military speakers raised questions to be answered by the scientists from their research data — questions which might provide the guidelines for the compilation of technical information into useful form. Prescribing the operational approach to visual search problems set the stage for a realistic and analytical discussion leading toward a definition of

the state of the art of search techniques. It was dramatically shown that visual search is "here to stay," i.e., that other *sensor systems might supplement but will never supplant the human eye tactically and strategically.*

Following the exposition of the practical aspects of visual search, there was a session comprised of reports on search strategies and probability functions. The statistical and temporal aspects of the possibilities of detection were presented, the ideal sensor system was discussed, and there was an analysis of the factors to be considered in developing optimal visual search procedures.

The basic characteristics of the human eye as related to search were then described. Through laboratory data and scientific research reviews, the inherent capabilities of the eye as a receptor, detector, and sensor were defined.

Visual performance was illustrated through reports dealing with the effectiveness of visual search in unstructured fields, complex displays and photographs, and in aerial surveillance and vigilance tasks.

Prior to the meeting, invited discussants received copies of selected papers and were asked to consider such questions as these: Have these papers contributed to our knowledge of visual search? From the information available, can we make recommendations concerning the development of optimal techniques and practices? Do any of these data answer the practical problems posed by the military participants? The comments of the invited discussants were presented as the final item in the various sessions. They constituted a timely synthesis and critique of concepts presented by the authors and were valuable both in themselves and in stimulating discussion from the floor. The prepared discussions and some of the extemporaneous comments made by other participants have been included in this symposium proceedings volume.

In retrospect, it seems increasingly evident that the Visual Search Symposium performed an important function by providing a forum for the exchange of information and ideas among representatives of widely diverse fields who share a common problem — that of determining the best techniques for visual search. The state of the art, as approximately established during the symposium, reveals that optimal procedures have not yet been developed. Military representatives at the symposium emphasized that information on effective search performance is needed *now*, and that future tactical planning requires further development of visual search techniques.

Various participants in the symposium emphasized that optimal visual search techniques are not and *cannot* be specified as such in any general statement. There are no quick and easy "do it yourself" rules in visual search. The choice of techniques is determined by variable circumstances and must be made in the light of specific factors in a given situation. The type and techniques of searching to be employed in an operational problem depend in every instance upon the answers to specific operational questions like these:

What is the target? What are its inherent characteristics and typical behavior? Just what are you looking for?

What is its environment? Where is the target expected to be? What is its background? Is it among other targets — in clutter, noise? What is its probable location relative to known landmarks? Is it obscured by intervening fog or haze?

What is the detector? If it is the human eye, how many eyes are available? What assists are used, such as optical aids, electronic enhancers, radar, etc.? How well trained are these eyes in standard search procedures and in recognizing this target?

How much time do you have? Searching takes time and the type of searching you can do will be determined by the time allowed.

What is the tactical significance involved? How important is it to find this target? What are the associated operational demands? How much would it cost if you missed it?

Listed below are a few of the many operationally useful recommendations for optimal search procedures which can be derived from the papers and comments recorded in these Proceedings.

Facilitate visual search —

By engineering design:
provide greatest possible visual field,
demand minimal visual time for operating and monitoring instruments, and
allow freedom of head movements to supplement eye activity.

By procedures employed:
fly low and slow if observer is airborne,
assign various sectors of the area to be searched to several observers,
rotate observers and limit observing time if possible.

By increased target visibility:
use anti-collision lights or proximity warning indicators on planes,
use high visibility paints for conspicuousness, and
use smoke, flares, dye markers to increase size and contrast.

Prepare the searchers —

Select observers on basis of visual characteristics; include tests for susceptibility to "blank-out" and for accommodation loss in empty visual fields.

Give adequate training and experience in actual or simulated situations.

Use successful observers, selected on basis of training evaluation.

Plan for search —

Assimilate *all* available tactical information related to the situation and forecast appropriately.

When searching —

Scan as fast as possible, providing brief, rapid fixations which cover greatest area in shortest time.

If time is unlimited, use automatic scanning exposure device to control sweep pattern and insure complete coverage.

Do not use binoculars for detection of targets expected to be at great or unknown range or if time is limited. The advantage of magnification does not compensate for field size restriction.

Use binoculars for identification of targets once located; search the target for recognition clues.

These fundamental "ground rules" will not apply in every case nor will they take the place of any detailed information that may be available.

Ailene Morris

U. S. Navy Electronics Laboratory
June 30, 1959

Acknowledgments

The need for this symposium was first pointed out by John M. Hood, Jr., of the Navy Electronics Laboratory, in July 1957. His enthusiastic support of the planning committees and the valuable assistance of Warren G. Lewis were largely responsible for the satisfactory conclusion of the efforts of the committees. Consultation and encouragement were generously extended by Robert M. Boynton, Carroll T. White, and James L. Harris. For two years Stanley S. Ballard provided the necessary liaison with the Vision Committee and, when the meeting was held, handled the logistic details. At the time of the meeting E. Porter Horne assumed the responsibilities of carrying the manuscripts and comments from rough copy through to publication.

A. M.

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OPERATIONAL BACKGROUND AND PHYSICAL CONSIDERATIONS RELATIVE TO VISUAL SEARCH PROBLEMS

EDWARD S. LAMAR

The problem of visual search has been one of great interest to me for a number of years. I am particularly gratified, therefore, to have this opportunity to talk to you on this subject. With such great emphasis now on electronic means of accomplishing various functions otherwise performed by people, one might ask with considerable justification, why we are still interested in the human eye as a search instrument. The fact of this symposium is proof enough that most of you believe this question has at least one answer. I believe it has many answers and will mention a few by way of illustration. Let us consider the human eye's chief competitor — radar. Most search radars act as pantographs to extend the range of search operations. The information received is still transferred to a human, usually through a visual link. The search problem, therefore, is still with us, merely transferred from the outdoors to a visual display. Again in connection with radar, the use of a military measure always stimulates the development of a countermeasure. To the extent to which this is done against radar, the human eye again becomes important as a primary search instrument. Finally, there are situations in which space and weight preclude the use of electronic equipment offering any advantage over the human eye. From even these few examples it would appear, therefore, that visual search, far from being of academic interest only, is a very live subject.

In order to make the most of the "Mark I Eyeball" as a search device, it is necessary to consider its various attributes in the operational setting in which it is to be used. This I shall try to do in the remainder of my talk. If most of my examples are from naval operations, it is simply because I am more familiar with this Service since the work on which this presentation is based was done for the Navy in what is now the Operations Evaluation Group (OEG) in the Office of the Chief of Naval Operations. If also I should suggest research which has already been done, it is simply because I have been out of this field for some time and am not up to date. The next two days should do much to cure this ailment.

Detection Lobes

Let us consider now some of the performance characteristics of the human eye which the evolutionary process has developed for search under daylight conditions of illumination. Seeing is done, of course, during fixations and any description of an operational search situation must be built up out of what happens during each fixation. The building block with which to begin is the volume in space covered in a single visual fixation. It is interesting to note that this volume is particularly well adapted to human survival. Distant targets which pose no immediate threat can be seen only if imaged on the narrow field of the fovea. The closer the target and hence the more immediate the threat, the greater is the fraction of the total retinal area over which the target image can be seen.

In more quantitative terms, a section through a typical detection volume is presented in polar coordinates in Fig. 1. Θ is the angle about the visual axis

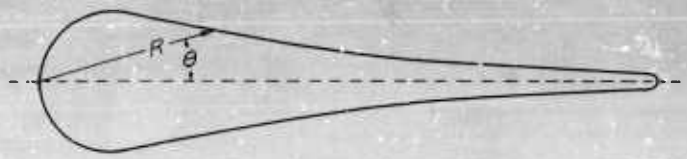


Fig. 1. Section through surface of revolution representing volume in space within which target can be seen.

within which the target can be seen, and R is the corresponding range within which the target can be seen for all angles equal to or less than Θ. Borrowing a term from the radar and sonar people, we can call the surface of revolution described by this curve the lobe pattern or simply the detection lobe. It can be thought of as attached to the eye and moving with it. Any target which falls within the lobe during a fixation will be seen and any target which falls outside will be missed. Actually, the boundary of the detection lobe is not as sharp as the diagram would indicate. Some targets just inside the boundary may be missed while others just outside may be seen. However, since the boundary can be so defined that these two effects compensate one for the other, we can proceed with the mathematical fiction of a sharp boundary with some assurance that the results will be the same as though the transition region had been considered in detail.

There is an equation from which detection lobes can be computed. This is presented as Eq. (1).

$$\begin{aligned} C &= 1.75\Theta^{1/2} + 45.6\Theta R^2/A \qquad (0.8° < \Theta < 90°) \\ C &= 1.57 + 36.5R^2/A \qquad (\Theta \leq 0.8°) \end{aligned} \tag{1}$$

Here C is the target contrast taken as the absolute value of the difference in brightness between target and background, divided by background brightness and expressed in per cent, Θ the angle off the visual axis in degrees, R the range in nautical miles, and A the projected area of the target in square feet. This equation was obtained by fitting some threshold contrast data taken by Craik at Cambridge during World War II. It is good over the values of Θ which are important in search. Both A and Θ were used as parameters in the experiments. While Eq. (1) has served a very useful purpose, much better data are available now from the work of Blackwell and others so that the time is now ripe for a re-examination of the whole problem. There are, of course, two other variables which have been neglected in Eq. (1). These are background brightness and target asymmetry. Neither of these variables is of any great importance under daylight conditions of illumination and, in view of the many additional uncertainties characteristic of most operational situations, can be neglected for all practical purposes.

While I do not wish to dwell on the details involved in the computation of detection lobes, I should not leave this subject without listing the transformations

of Eq. (1) required to make it operationally useful. These are as follows: The contrast C is re-expressed in terms of intrinsic contrast C_0 and meteorological visibility V in accordance with Koschmieder's Law. The constant employed in doing this is appropriate to the sort of visibility test objects, mountains or high coast lines which are available to ships at sea. Next, the equation is rearranged in terms of R_0/R where R_0 is the foveal range under conditions of unlimited visibility. R_0 is the value of R obtained by setting $\Theta = 0.8°$ and $C = C_0$ in Eq. (1). Finally, two new variables F and G are introduced to facilitate computation. In these terms

$$\Theta = F(\sqrt{G/F+1}-1)^2$$
$$F = 0.49(R_0/R)^4/(C_0-1.565)^2 \qquad (2)$$
$$G = 0.80C_0(R_0/R)^2 \exp(-3.44R/V)/(C_0-1.565)$$

Visual Search

Having developed our basic building block, we are now ready to consider some operational search situations. Before doing so, a few words about the need to consider search situations at all seems appropriate since it is not immediately obvious why we do not always pick up a target at foveal range. I am sure you have all had the experience, particularly when in a hurry to dress for a formal affair, of dropping your last collar button on the floor. Usually many minutes elapse before it is spotted. When it is spotted, it is easily visible foveally but undoubtedly was picked up in the periphery first. In short, search takes time. During that time a target, particularly an aircraft, can travel a long way. Detection ranges, therefore, are usually reduced below those characteristic of the fovea. If we are to plan operations depending on the human eye, we must take into account these effects of time and speed as well as the response of the eye to a visual stimulus.

Let us begin with a representative two dimensional situation as illustrated in Fig. 2. The search craft is situated at the origin of coordinates. We are interested

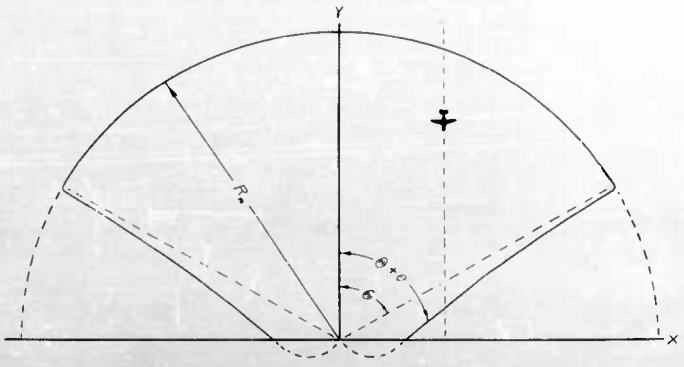


Fig. 2. Two dimensional search situation with observer at origin of coordinates.

in a target coming in along the course shown and wish to determine the chance of detection before the target reaches the point (x, y). R_m is the foveal range under existing visibility conditions and 2Θ is the angle about the y axis through which a lookout is scanning. In any given fixation, the chance of detecting the target is simply the chance that the target is within the detection lobe. Since this lobe may be pointed in any direction within the angle 2Θ, this is simply the ratio of the angular width of the detection lobe to the angle searched. This chance or probability we call g, the glimpse probability, and is given by

$$g = 2\theta/(2\theta + 2\Theta) = \theta/(\theta + \Theta) \tag{3}$$

as can be seen from the geometry.

Let us assume to begin with that each fixation is an independent event. Then the probabilities of detection for the various fixations combine in accordance with the usual probability laws for independent probabilities, i.e., the failure probabilities multiply. If then we number the g's successively, we have

$$P(x, y) = 1 - \prod_{i=1}^{n} (1 - g_i) \tag{4}$$

P(x, y) is the probability of detecting the target by the time it reaches the point (x, y) and $\prod_{i=1}^{n} (1 - g_i)$ is the product of terms of the form $(1-g)$ for all integral values of i from 1 to n. While again I do not wish to burden you with mathematics, some transformation of Eq. (4) is necessary before it can be very useful. I will run through the necessary steps quickly. First of all, a product is not as nice to deal with as a sum so we will rewrite Eq. (4) in logarithmic form.
Thus,

$$P(x, y) = 1 - \exp\left[\sum_{i=1}^{n} \log (1 - g_i)\right] \tag{5}$$

Now for a given x, g_i is a function of y since θ on which it depends is a function of y. If g_1 is taken at the edge of the R_m circle, g is a function of y_m. If Δ is the distance traveled between fixations, then g_2 is a function of $y_m - \Delta$; g_3 of $y_m - 2\Delta$, etc.

Actually, the first fixation after the target enters the maximum range circle may occur when the target is anywhere between y_m and $y_m - \Delta$. Hence, for the g_i term we need the average value of $\log (1-g)$ over the interval between y_m and $y_m - \Delta$ or

$$\log (1 - g_i) = (1/\Delta) \int_{y_m - \Delta}^{y_m} \log (1 - g)\, dy \tag{6}$$

Taking similar terms for the successive g's and summing as indicated in Eq. (5), we find that each integral is of the same form and that the lower limit of one corresponds to the upper limit of the next one. The whole series summation, therefore, can be replaced by a single integral with proper limits. Thus,

$$P(x, y) = 1 - \exp\left[(1/\Delta) \int_{y}^{y_m} \log (1 - g)\, dy\right] \tag{7}$$

Finally, Δ is the product of the fixation time T and the velocity v. Hence,

$$P(x, y) = 1 - \exp\left[(1/vT) \int_{y}^{y_m} \log (1-g)\, dy \right] \qquad (8)$$

Eq. (8) is the result we have been looking for. Now let us examine the various terms to see what they mean physically. First of all, let us look at the integrand log $(1-g)$. Since $1-g$ is always less than unity, the integrand is always negative. The smaller the value of $1-g$ the greater is the negative value of the integrand; hence, the smaller the whole exponential and the greater the probability of detection P(x, y). You remember that g is the chance of detecting the target in a single fixation. It makes sense, therefore, for larger g's to produce larger values of the probability of detection P(x, y).

Now let us consider the influence of the fixation time T on the probability of detection P(x, y). Since it is in the denominator of the exponential, the smaller it is the greater is the value of the negative exponent and again the greater the value of P(x, y). This again makes physical sense since the smaller T, the greater the number of fixations we can make while the target is coming in to the point x, y provided of course that T is long enough.

Finally, the target velocity v also enters in the denominator of the exponent and thus has exactly the same effect as T. The smaller the velocity v, the greater is the time taken by the target in getting to the point x, y and the greater the number of fixations which can be made during its passage.

Now let us go back to Eq. (3) and see what influences the single look probability g. Eq. (3), of course, refers to a two dimensional situation in which search is confined to a single line. If search in elevation is also required, then g becomes the ratio of two solid angles rather than two linear ones, i.e.,

$$g = \Theta^2 / (\Theta + \Theta)(\Theta + \Phi) \qquad (9)$$

where Φ is the corresponding elevation angle through which search must be carried out. Clearly the smaller the angles Θ and Φ the larger the value of g. If we have to search the whole sky, the chance of seeing a target in a single fixation is pretty small. If on the other hand, we have advanced information which allows us to restrict our search so that Θ and/or Φ are reduced, our chances go up. Often we know in a general way the direction from which an enemy must come and, hence, can take advantage of intelligence to restrict our search. In air intercept situations, fighter director radars can usually tell the pilot approximately where to look, thus restricting the volume of uncertainty and facilitating visual tally-ho. Finally, we can use more than one lookout and divide the job up among them. Θ and/or Φ thus becomes reduced for each so that g goes up.

One possible means of increasing the values of g which at first sight appears attractive is the use of binoculars to increase the range. Binoculars for this purpose constitute a mixed blessing. Without going through the equations, I believe we can see qualitatively what is involved. Under haze free conditions, binoculars increase the apparent area and, hence, the range at which a target can be

seen. In detection lobe terms, they increase the value of R for each value of Θ. They also increase both Θ and Φ thus tending to decrease g. Binoculars also restrict the field of view and throw away the advantage of the fat portions of the detection lobe. One can say in a general way that if the limit on search is range and not time required to cover the field, then binoculars will assist in increasing the value of P(x, y). If, on the other hand, the chief limitation is time to cover the field, then binoculars can actually reduce the value of P(x, y) since they both increase the field which must be searched and restrict the fraction covered in any one look.

Another variable which needs closer examination is T the fixation time. Craik found that with forced scanning this time was as low as 0.25 seconds. However, the data from some line search experiments which he carried out in the laboratory could be fitted only by assuming T to be about 1.5 seconds. The first operational data good enough to check this value were some taken by Cdr. Leavitt whom many of you may remember as a member of the Vision Committee. I had the pleasure of analyzing these data and found again about 1.5 seconds actually 1.65 as the parameter T required in Eq. (8). My guess as to what this means is that an observer either uses half a dozen short fixations or one long one in each direction before moving on. Whether or not observers can be trained to move faster thus reducing T or whether such a reduction would also reduce g, I do not know. It is one problem which bears looking into since a potential factor of 6 gain is quite important for military operations. It would be the equivalent of using six lookouts instead of one.

Experimental Results

So far, I have discussed the theoretical formulation of the search problem. Now with regard to experimental verification, time does not permit the presentation of all the work which has been done. I will confine myself, therefore, to mention of the three projects which were carried out in the OEG and with the presentation of a sample set of results from the third project. The first work done during the war consisted essentially of fitting Eq. (8) to visual sighting data obtained from aircraft sightings of German submarines in the Bay of Biscay. While the fit was good, the constants involved were difficult to tie down in detail because of lack of knowledge concerning the angle Θ which was searched. The second project consisted of fitting the data taken by Cdr. Leavitt in connection with air-sea rescue operations. These were beautiful data taken under well controlled conditions. As a result of the checks obtained with theory in this instance, the OEG proceeded with considerable confidence to make calculations for use in other operational situations. Finally, some trials were made at Patuxent in connection with air intercept. These are the data I shall show presently.

Two aircraft were employed, each acting as target for search by the other. The object of the trials was to compare measured and computed detection probabilities. Tracking runs were employed to determine some of the parameters required for the computed values. The trials were run with the sun sufficiently high to insure that the illumination of the target was sky illumination and the back-

ground sky background. The intrinsic contrast was then computed from the reflectivity of the paint. The areas were measured from photographs so that R_0 could be computed. Before each detection run the range was opened and the target plane tracked. Knowing R_0 and the disappearance range, the visibility was computed. This completed the information required to compute the detection lobe. Following the tracking run, the range was closed in a detection run. Each aircraft used a prearranged scanning procedure about the expected direction of the target using values of Θ and Φ agreed on before the trials. The closing speed was also known so that the probability of detection P(x, y) in this case P(O, R) could be computed. The fixation time T was taken as 1.65 seconds, the time obtained from Cdr. Leavitt's experiments. The various ranges were obtained using tracking radars on the ground.

After the series of trials was completed, the detections were arranged in order of decreasing R and a cumulative sum computed for each value of R. This sum for each value of R divided by the total number of runs provided a measure of P(O, R). The theoretical curve and a typical set of experimental points are presented in Fig. 3. Altogether, 131 detection runs were retained for analysis. The

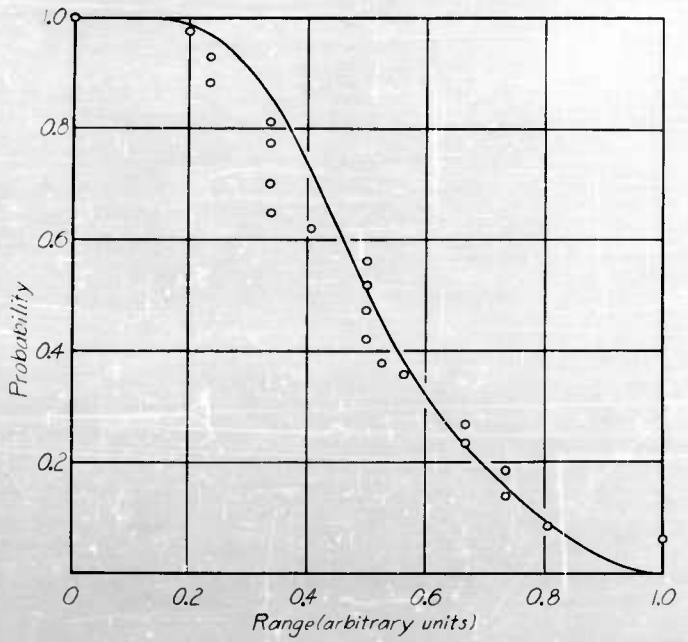


Fig. 3. Sample check between measured and computed detection probability for air intercept. Solid line is the computed curve. Points are experimental.

chief reason for discarding a run was specular reflection. Of the 131 observations, 48 per cent were within the 80 per cent confidence limits.

It would appear, therefore, that the theory is satisfactory under conditions which can be checked. There are, however, many situations in which we do not have the data from which to compute the detection lobes. When the sun is low, looking down sun the target is illuminated not by the sky but by the sun directly and hence appears brighter than the background. Up sun the target shadows the bright sky and hence appears dark. Somewhere in between the target may even match the background. Sometimes targets are in the shadow of clouds while at other times they are illuminated by scattered light from the clouds. There is, therefore, a large number of conditions of operational interest where work in atmospheric optics is needed before we can compute operational search results. Much of this work has already been done by Duntley and others so that it is largely a matter of using existing data to describe specific operational situations. The aircraft people, both military and civilian, are acutely aware of the blind azimuths just mentioned and such things as stripes and luminous paints are being tried to eliminate them.

Visual Displays

So far, I have discussed the use of the human eye for primary search only and have pointed out areas in which I believe further work is needed. As I mentioned earlier, electronic equipment is gradually replacing the human eye as a primary search instrument. As this trend progresses, the emphasis on vision research for military purposes will no doubt shift to problems involving visual displays. My talk would not be complete, therefore, without some discussion of the problems involved here. Visual displays of electronic information can be divided roughly into two types. In the first, a target indication consists of a brightening or darkening of a spot on a display. In the second, a target indication consists of a displacement of a display trace from a base line.

With regard to the first, the intensity modulated display, it would seem that we need merely to search the solid angle subtended at the eye by the visual display and the theory developed for primary search would carry over in toto. I am not at all certain that this is the case. Often a target indication is clearly visible well out into the periphery of the retina and hence should be easy to detect. However, so also are false indications resulting from noise. It may be then, that the target indication must be examined using smaller values of Θ in order to obtain sufficient resolution to distinguish target indication from noise. Since noise often appears as a distinct false target rather than as an increase in general background, care must be taken in simulation experiments to insure that noise as well as signal goes through the electronics as in the equipment simulated. While a great deal of research has been done on intensity modulated displays, it is my belief that a great deal more is needed before we can consider them completely understood.

There is good reason to believe that the displacement type display is somewhat better than the intensity modulated type for detection. It would appear

that it is somewhat easier to distinguish a displacement from a base line than it is a change in contrast. These displays have been neglected in recent years largely because of other advantages of intensity modulated types. While a great deal of work has been done by the group at the Tiffany Foundation during the war and others since on contrast discrimination, I know of no parallel work in the field of displacement discrimination. It would appear, therefore, that here is a fertile field for basic research for which there is an immediate practical pay off.

Conclusion

In closing I would like to say that in spite of the rapid advances in electronics, the human eye still constitutes an important instrument for primary search. Electronic equipments using visual displays are not competitors of the human eye, but aids to extend its range beyond that set by physiological limitations. The best match between the display and the human eye constitutes a real challenge for research on human vision. This audience represents the talent required to solve the problems involved both in primary search and display-aided search. In the next two days we will hear papers bearing on all the problem areas I have mentioned and many others. We shall hear of progress in these areas and ideas for further advances. I feel certain that in the papers presented, in the discussions which follow, and in the exchange of ideas throughout the meeting, we will all enjoy a stimulating and useful two days.

VISUAL SEARCH TECHNIQUES FOR AERIAL SURVEILLANCE

HENRY F. HAUSER

Introduction

Reliable and timely intelligence of enemy dispositions and movement is vital to the conduct of operations. Air surveillance is an important source, but only one of many sources from which the general enemy situation is built. Therefore, intelligence from visual air observation must be utilized in conjunction with intelligence obtained from all other sources, if time permits. It is of paramount importance that the capabilities and limitations of visual air surveillance be familiar to all commanders and staff officers in order that more effective utilization can be made of this capability.

The work of an aerial visual surveillance observer may not attract the same attention as that of a fighter pilot. The observer's enthusiasm must be maintained by the knowledge that the intelligence he obtains and the speed and accuracy through which he disseminates the information is not only of great value but is also being put to full use. The ground commander through his intelligence officer must know what he requires and must explain clearly and concisely why, and when, the intelligence is required. The primary object of the air visual observer is to obtain intelligence and either radio the information back or bring the information back for quick post mission review.

One of the greatest difficulties confronting aerial observers in the battle area is to distinguish friendly forces from enemy and to identify targets which are of significance. The speed of modern aircraft and the operational height at which they sometimes are required to fly make the recognition and identification of targets on the ground a difficult matter. Many targets such as gun positions, strong points, and tanks in defilade are small and are hard to see from the air, particularly when camouflage measures have been applied. They may also be close to our own troops. Maps may be inaccurate or the terrain may be featureless. For these and other reasons, the following aids may be employed to assist aircrews in the positive identification and location of these targets.

Aids can be provided either visually or by radar and radio assisted approach. When the pilot is navigating visually to his target area he depends upon landmarks to check his position and course. If the terrain is such that these landmarks do not exist, then the Army may be called upon to provide artificial landmarks. These may be required by day or for certain night missions. Examples of artificial landmarks are temporary recognition displays including colored fluorescent panels, flares, colored smoke, ground strips, and radar and radio devices.

Application to Target Acquisition

Aerial surveillance has the greatest potential for rapid delivery of accurate information on the enemy. No other system of collecting intelligence penetrates enemy territory as deeply, thoroughly, and frequently as aerial surveillance. The increased range of new weapons has brought to the fore the problem of target

acquisition, particularly in the compilation of intelligence data with methods more rapidly and accurately than previously required. With effective visual surveillance planning, the capability of visual surveillance is increased to the point where its effectiveness more closely approaches the optimal goal of continuous surveillance, particularly in the areas of target acquisition.

Present Capabilities of Visual Surveillance

The Army organic visual surveillance capabilities today rely mainly upon the L-19, L-20, L-23 and helicopter aircraft. All of these are relatively light, slow moving and have a rather limited operational radius. At present, organic manned aircraft are useful in the visual surveillance role only in the front line areas and cannot be employed in the deeper penetrations which we are considering essential in future concepts. For surveillance requirements in support of a Field Army we are now considering an area 100 miles wide and 300 miles deep into enemy territory.

Visual surveillance information, invaluable to the ground forces, many times never reaches the user, due to lack of communications and the rapid displacement and mobility of units.

Present state of training of visual observers precludes accurate and immediate evaluation of target information.

The support of Army operations by Tactical Air Force is primarily conducted by reconnaissance-fighter type aircraft. In the visual observation role, the capabilities of these fighter-converted aircraft are limited, in that it is necessary for the pilot to conduct visual observation at the same time he is operating the aircraft and watching for enemy air operations. In addition, the high speeds of these aircraft have increased the major problem of visual aerial observation; namely, that rapidly changing the observer's position relative to the area observed. However, their high speeds make these aircraft less vulnerable to enemy counteraction, and permit them a greater depth of penetration without fear of being shot down.

In developing the tactical concepts and the visual surveillance requirements needed to support them, increasing emphasis is being placed on the time element as well as on the accuracy of the located targets.

Army organic manned aircraft are designed to do a specific job. Of great concern to us is that we must place in this aircraft a well trained visual observer. The success in the directed employment is hinged upon the careful planning and coordination required mainly by the Army Aviation Officer, the G2 Air, Ground Liaison Officer, the FDC, G3 Air, Air Force Air Operations Center, and the Signal Officer.

Types of Visual Surveillance Missions

There are five general types of visual surveillance: area search, specific search, route surveillance, artillery adjustment, and contact surveillance.

(1) Area Search — That part of enemy-held territory, where regular surveillance is required, is divided into clearly limited and defined areas required in support of the Field Army.

Any of these zones may be subdivided for area search surveillance. The size of the sub-divisions or individual areas is determined by such factors as the nature of the terrain, the intensity of search desired, and the number of surveillance aircraft available daily to exploit these areas. Each area is searched at regular intervals to check and report on current enemy activity. This type of visual surveillance is economical in effort, is especially suited to sparsely populated or open country, and additionally, provides the timely reporting of information.

(2) Specific Search — As distinguished from area search, this type of visual surveillance is used to reconnoiter a limited number of points for specific information. Specific search is suited to close or densely populated terrain. It may sometimes be used to supplement the regularly scheduled area search missions.

(3) Route Surveillance — Route surveillance covers roads, railroads, and waterways in and beyond the areas where regular search is used. It is carried out on a point-to-point or town-to-town basis over enemy main transportation arteries. Assigned routes may extend through several areas where regular area search is conducted to points deep beyond the FEBA.

(4) Artillery Adjustment — In addition to Army organic aircraft, high performance aircraft may be used to adjust artillery fire when the targets cannot be observed from the ground. They may also be used for surveillance of targets or for adjusting fires of long-range weapons other than conventional artillery.

(5) Contact Surveillance — If a friendly unit becomes isolated from, or loses communication with the main body, it may be necessary to dispatch an aircraft to locate and communicate with the isolated unit. As in the case of artillery adjustment, high performance aircraft should be used only when the mission is beyond the operational capabilities of slower organic aircraft.

It is not normal to assign more than one type of surveillance to one surveillance mission. However, when it appears that an artillery adjustment mission will be of short duration, the pilot or visual observer may be briefed to carry out route surveillance or specific search when the artillery adjustment has been completed. Similarly, a mission assigned to area search may conduct route surveillance en route to and from the area.

Types of Surveillance Targets

Targets for visual air surveillance are classified as fixed, transient, and fleeting.

(1) Any object or structure which is not subject to movement is classified as a fixed target. Visual air surveillance missions scheduled for fixed targets are usually supplemented with photo missions or by the visual observer taking photos of these targets.

(2) Transient targets are classified as structures for temporary use. This type target includes such military installations as camps, bivouacs, supply installations, ammunition dumps, and ponton bridges.

(3) Fleeting targets are objects that move, such as concentrations of troops, vehicles of all kinds, watercraft, and aircraft.

Visual surveillance missions are usually employed in preference to photo missions in gathering information about transient and fleeting targets. This is obvious; since, if taken by photo missions, the movements would take the targets to other areas by the time the photo imagery is processed and interpreted by image interpreters.

Kinds of Targets Commanders Are Interested In

Front line commanders and their weapons officers (company, battalion, battle group) are interested in the location of automatic weapons, antitank guns, individual tanks, pillboxes, mortars, light artillery and such other enemy activities which are predominantly fleeting in nature, but may include semi-mobile and fixed targets.

Division and Corps commanders and their weapons officers are interested in the location of missile launching sites, medium and heavy artillery, reserves, assembly areas, command posts, supply points, and such other enemy activities which are predominantly semi-mobile in nature, but will include some fleeting and fixed targets.

Field Army, Army Group and Theater commanders are interested in long range missile launching sites, marshalling areas, communication centers, nuclear stockpiles, strategic targets such as manufacturing centers and hydroelectric dams.

The G2's at each echelon (division, battle group, corps, and Field Army) generally require that type of information which:

(1) Indicates or substantiates a build-up or concentration of enemy personnel and/or materiel.

(2) Divulges terrain and cultural features whose use by the enemy will materially assist the accomplishment of his mission and/or whose use by U. S. forces through occupation, isolation, or destruction, is necessary to the accomplishment of the U. S. mission.

Visual Observer Skills

Visual surveillance is one of the primary sources of intelligence information on enemy activity beyond the limits of front line observation. The information obtained by visual surveillance so derived concerning transient targets becomes progressively less reliable as the time interval (sighting to reporting) increases. The information gained relating to fixed installations usually requires no verification, providing such fixed installations can be adequately identified and located. The enemy's deceptive ability and the extent to which the enemy uses under-

ground facilities affect the efficiency of the highest trained visual observer. Except as a more experienced visual observer may be able to detect indications enabling him to overcome the enemy's deception effort, there is no particular increased requirement relating to skills of visual surveillance for this type installation.

Locating, identifying and describing enemy transient target information is the area in which the greatest skill is required. Many of the problems connected with this area of visual surveillance are not a function of observer skills but rather of the capabilities of the target itself. The greater the degree of skill and abilities as an observer, however, and the broader the base of experience, the more accurate and detailed will be the indications pointing toward transient enemy activity.

The accumulative data derived from continuous visual search over the same areas will establish the presence of a potential target for modern U. S. weapons to engage. Once the location of the target has been determined its movement must be the subject of continuous surveillance in order to ascertain its exact location at a specified point and time. Before the target is engaged many factors of importance to the commander must be considered. Most of these are outside the scope of duties of the most experienced visual observers.

In the Division zone of primary interest, special visual search skill requirements in connection with modern weapons are less critical than at higher echelons because of the nature and relative location of the target. Other means of location, detection, and surveillance of targets are readily available to Division. Location of the targets is such that many other organic means can produce required data.

In that part of the Corps zone of primary interest not accessible to ground collection agencies dependence on visual surveillance and on photo image interpretation is much greater than at Division. In this area substantiating sources are normally not available. Visual searchings must be most timely, accurate and reliable.

Field Army requirements are the most specific and at the same time cover the greatest area. It is in this area that initial target information must be developed from "unit watching" on a wide scale and from areas of logical or historical approach. Dispersion will be maintained by the enemy until the last possible moment — before achieving the necessary mass to accomplish his mission. The detection of the movement of the elements of this mass while still dispersed, prediction of the direction of movement, probable strength, composition and point of action are essential to prevent tactical surprise. (This — regardless of whether movement is achieved day or night; on the ground or underground. This sets up new requirements for the visual observer.) Just like in photo image interpretation, detailed specific area surveillance must be analyzed together for all the areas in and adjacent to the Army Zone of Action.

Effective Altitude of Visual Surveillance Missions

Visual surveillance missions are flown from "on the deck" at levels from 50 to 500 feet and upwards from 5,000 to 8,000 feet.

The 5,000 to 8,000 foot range is above the maximum effective range of automatic weapons. When flying at this level, the pilot and/or visual observer can detect vehicles and distinguish movement to about 5 miles on each side if the visibility is good. Since this range decreases as visibility lessens, a strip about 10 miles wide is the maximum area that a surveillance observer can cover effectively under optimum conditions.

When flying "on the deck", the pilot and/or visual observer can see little more on each side of a road than can be seen from an automobile. The principal reasons for flying at this altitude are to get under low clouds, or to approach undetected a suspected object for identification purposes. When flying at this level, the pilot depends on speed to get into and out of the target area before being fired upon by enemy automatic weapons.

It is apparent that there will be times when weather will prohibit the use of either, or both, of these levels. With a low cloud ceiling, limited observation can still be conducted "on the deck" if the terrain is relatively flat. If the terrain is mountainous, hilly, or rolling, and the cloud rests on the ground at or below the tops of the terrain prominences, visual surveillance missions cannot be flown.

Limitations of Visual Surveillance

The effectiveness of visual surveillance missions is limited by the visual acuity of the pilots who fly the missions and the observers who fly with them. For example, at 3,000 feet altitude a tank can be identified. The turret and the gun projecting from the turret can be seen clearly. At 5,000 or 6,000 feet the eye loses the ability to distinguish the gun. The shape of the turret can still be distinguished, however, and a tank may still be identified as such. This is especially true if there is enough sunlight so that the turret casts a shadow, which will aid in identification. At an altitude of 10,000 feet the eye can no longer distinguish the turret, and the tank appears as a rectangular object.

At 3,000 feet altitude, artillery pieces can be distinguished. The gun barrel is visible. At 6,000 feet, the same thing happens to the gun behind the truck that happened to the gun on the tank. All that can be seen is a large vehicle towing a smaller vehicle. At 10,000 feet this picture is still further reduced. There is also, the possibility of confusing artillery vehicles with supply vehicles. At 3,000 feet an artillery prime mover and its trailer can be identified because of the barrel of the gun. At 6,000 feet altitude the artillery and the supply vehicles become indistinguishable.

Other limitations to the effectiveness of visual surveillance missions are imposed by the very means by which the observer is transported. He works under the double handicap of attempting to examine an object while flying over or near it at a rather fast speed, and of being able to devote to the examination only that part of his mind which is not engaged in flying a fast aircraft, and in keeping himself oriented geographically.

When visual observers employ their camera equipment, if they have it, to supplement their visual observations, the limitations above are substantially

diminished. The detailed accuracy of their information increases, but the time required to land, to process the films, and to interpret the photo imagery is such that information about fleeting targets is largely useless by the time it is available.

The factor which overcomes these limitations is the speed with which information about fleeting targets can be relayed to friendly units who are capable of attacking these targets before they cease to exist.

Requests for Visual Air Surveillance

Normally, requests for visual air surveillance will include the following minimum information:

(1) Areas, routes, or targets to be covered.
(2) Time the coverage is desired.
(3) Significance of desired information (justification for request).
(4) Specific information desired.
(5) When the friendly artillery may cease firing.
(6) Ordinates of ground fires in the area to be searched.

Prerequisites of a Visual Observer

He must have a reasonably good mental picture of the area(s) where he is to observe. He builds a mental key of these areas by studying the best maps and charts of the area(s); studies mosaics and stereoscopic study of selected photo imagery of the area(s); has a mental picture of how his friendly front line units are deployed and their primary objectives; knowledge as to how the enemy units are deployed. This is obtained from the situation map and through special briefings.

He must know the dominating terrain features and landmarks which lie between his location and the target areas he is to reconnoiter.

He must know built-up areas, towns, villages, farms, etc., and where they are with relation to the target area(s).

He must know where main highways, rivers, and streams are with relation to the target areas.

He must know what areas are heavily vegetated; where open terrain is.

He must know the best altitude to fly his missions under varying terrain and weather conditions and yet be able to detect, identify, and locate important targets.

He should have a methodical means of plotting or indicating on his map (photo or mosaic) accurately the targets he identifies and determine the significance or status of the identified target(s)

He must be able to detect slight variations in appearance of vegetation and contour and to identify topographical features and works of man during visual searchings.

He must have thorough knowledge of what military installations look like from the air and have a good understanding of tactical employment of ground and supporting troops.

He must have a good foundation in map reading and major units of instruction in photo image interpretation.

He must know what effects camouflage has on equipment and how to identify targets which are camouflaged.

He should be suspicious of unusual and recent track activity made by foot troops as well as vehicular.

He should be able to pick up indications or signatures from the air as to any activity or presence of personnel and/or military equipment and analyze these in terms of what they are associated with.

He must be a graduate of photo imagery interpretation school.

He should be mentally alert, be interested, have good eye sight.

Visual Search Techniques

Military targets vary enormously in size and physical characteristics and present an infinite variety of very complex configurations. These types of targets will usually be of variable luminance due to the amount of light present at the time observed as well as the shadow patterns cast by the targets.

As far as the observer being able to detect better circular shaped targets from square, rectangular or trapezoidal shaped targets, I cannot say; however, I do believe that, if the visual observer applies himself as does the photo-image interpreter, he can deduce what he is seeing by merely applying a mental system of target analysis. He would do this by first determining whether what he is seeing is a target, then associating this with its surrounding environment. This latter stage in the analysis would tend to prove the significance (tactically) and might even disclose or tend to direct the visual observer's eyes on the associated features of a target complex. This mental analysis is even more significant in that a target complex with all its related features could be identified and located.

It should be understood that the visual observer during a surveillance mission should be alert and seek out information concerning enemy dispositions, his equipment and kinds of personnel in their natural environments as dictated by battle tactics. He accomplishes this search by vigilant sweep through conditions such as atmospheric haze, illumination, and light mediations. These have to a considerable degree certain effects on his ability to locate accurately, identify, and describe targets.

Whether the observer's unaided eyes are focused on a concentration of enemy riflemen or are fixed on what might logically be identified as a missile launching site, the stimulus conditions might very well be the same as confronted by a photo-image interpreter. The latter, when searching for information to be ex-

tracted from the photo image, is usually confronted with such characteristics as image scale, granularity, sharpness, density, and contrast. In either case, the visual observer or the photo-image interpreter is concerned with time element, recognition responses and certain stimulus variables required for the recognition and location of targets. What these targets look like and what form of silhouette they present on the ground are some of the problems running through the minds of visual observers. Needless to say, the more experienced this observer is, the more reliable, timely, and accurate his information will be.

The mind of the visual observer has to function similarly to that of the photo-image interpreter. He must be a tactician; he will try to have a mental picture of where the enemy troops are, and where are they going. Lastly, is there anything significant in the manner in which they are operating? The observer must mentally convert himself to the thinking of the enemy G3 and ask questions of himself, i.e., where are the Infantry troops located, where would the most logical place for supporting artillery be; where are the tanks; are the tanks in general support of the Infantry; are they in reserve; where are the Engineer troops most likely to be located; will the foot troops utilize cover afforded by wooded areas; will they make use of draws along stream beds, or will they move across open terrain; will the vehicles be bound to the primary roads or will they use secondary roads; are the vehicles dispersed, or will they be in large concentrations for leap-frogging movements?

It was mentioned previously that the mind of the visual observer works similarly to that of the photo-image interpreter. The conditions for viewing are similar since both are looking downward on the terrain. The basic difference is that the photo-image interpreter is more relaxed and might be seated in a comfortable chair looking through a stereoscope. The visual observer on the other hand, is riding in an aerial platform in a crowded compartment and under mental strain. His environment is different but his technique for detection, identification, and location of objects or installations are very much the same as that of the image interpreter. If we can agree on this point, let us then take a hypothetical situation and try to analyze how a good visual observer might apply himself in the performance of his task.

(1) The visual observer has been briefed on the enemy situation by a GLO (Ground Liaison Officer). He has a good idea from the G2 situation map where his own friendly troops are, what their primary objective is, and, of great consequence, the locations of certain main enemy units. The Assistant G2 Air Staff Officer at the Army airstrip has shown the visual observer the surveillance requirements for the Division as planned for the next day. He also, because of prior missions, elected to put the observer on an *area surveillance mission*. This is indicated on a map and is appropriately marked as to frequency of surveillance and number of aircraft to be employed. Let us say for practical purposes, the area covers a six mile square adjacent to a small town located some 15 miles into enemy territory from the forward edge of the battle area (FEBA).

(2) The area surveillance mission is scheduled for an early morning mission, 0500 hours. The visual observer gets about five hours of sleep, is awakened in

time for an early breakfast, and has a last minute check with the GLO before moving down the runway at 0502 hours. Probably several things are going through his mind as the wheels of his L-23 are clearing the last bit of the dirt runway. The morning clouds are broken and the reflections from the sun's rays in the East make him realize that he is out to do a job, a very important job and furthermore, he must get this job accomplished during these early morning hours.

(3) He is now climbing to an altitude of 5,000 feet and heading generally toward Vodiniski, the town lying south of the area to be searched. The observer in the meantime has already located from the air his friendly, front-line rifle companies and he has seen an occasional enemy truck, but his mission requires him to get to the area north of Vodiniski and obtain vital intelligence information about that area.

(4) According to the Essential Elements of Information (EEI's), our observer was informed that the Division Commander concerned had requested that all information forwarded to the Division would include the time targets were observed, by what unit observed, and place where observation was made. All reports from the information-gathering agencies would answer the questions: *Who, What, When, Where,* and *How.* As a result of information obtained from interrogating a "line crosser" from the town of Vodiniski, it was reported that considerable activity was observed in the wooded area north of the town. The informant noticed heavy trucks laden with heavy construction materiel proceeding to the wooded area every day for one week. He also observed heavy construction equipment moving to the same area.

In the distance our observer makes out the outline of an inhabited area. He checks his map and recognizes this area to be Vodiniski. The pilot is setting his bearing for the wooded area just north of the town (of Vodiniski) the area to be searched. It is now 0510 hours and daylight is just breaking. With his map on his knees the observer is orienting himself with relation to the ground. To his front an excavated area in the near edge of the woods immediately distracts his attention. As he approaches within approximately a half mile from this excavation he notices what appears to be a large opening, like a cave, at the center of the excavated area. Leading to this "cave" from two different directions are paved roads capable of accommodating two-way traffic. Adjacent to the entrance to the "cave" the observer makes out the faint outline of what appears to be railroad track. By getting the pilot to follow the hard surfaced roads leading to and from the excavated area, the observer notices two small buildings, apparently of heavy construction, partially covered with soil approximately two miles from the first detected excavation. As they commence circling these buildings, the observer determines that the buildings are being covered with soil probably hauled from the large excavated area first observed. At approximately three miles to the northeast a larger building, also of heavy construction, is detected. Also noticed was that this building was connected by another wide, hard surfaced road leading to the two small buildings observed southwest. He makes out another hard surfaced road leading from this building in an east-west direction, apparently all the way to the large excavated area where the "cave" was first observed. By carefully

scanning the terrain northeast of his present position he makes out the outline of a sizeable airfield just outside of a town considerably larger than Vodiniski. Checking his map he identifies the town to be Caviarski. The main highway from this city passes the airfield and leads to Vodiniski. His pilot turns back to the portion of the wooded area between the outer limits of Vodiniski and the large heavily constructed building observed three minutes before. Much to his surprise he noticed three trailers with sizeable tanks, two large tank trucks, like gasoline trucks, and seven very long trailers, possibly 70 feet long, with their prime movers, all dispersed under the heavy foliaged area. The time is now 0525 and the pilot is directed to make a pass over the previously cited constructions. The large building, appearing like small concrete warehouses, are being draped on the edges with foliage, possibly attempts to camouflage. Proceeding on to southwest they are again over the two small buildings being covered with soil. With another look at the configuration, the observer notices a well paved road leading into both ends of these buildings from the main road. This look at the buildings convinces the observer that, whatever these buildings are, their construction work is completed and the soil covering these is for camouflage purposes. They are now passing over the first sighting, the large "cave." A closer look at this installation reveals to the observer that this is a heavily reinforced underground structure having sliding doors and has a small concrete apron extending from the opening of the underground installation. He makes out what appears to be a narrow gauge railroad connecting the underground installation with the concrete apron. It is now 0530 hours, the sun is clearly visible over the horizon and the Army organic aircraft is heading towards "home." What is in the mind of the observer will now be summarized briefly.

Deductions

(1) The "lead" to the activity in the wooded area was at first started by information derived from the "line crosser" who had lived in the town of Vodiniski.

(2) By having an adequate briefing by the GLO (Ground Liaison Officer) and the Assistant G2 Air at the Army airstrip, the observer had a thorough mental picture as to where our friendly troops were located, where certain main enemy units were and more specifically, the area to be searched for the vital information requested by the Division Commander.

(3) The first detection of the "cave-like" installation, the roads leading therefrom, the additional heavily constructed buildings with interconnecting roads at first didn't mean too much. The observer at this point started his mental analysis. His first question to himself was — why would a cave be dug in a forest lying just north of the town of Vodiniski? Was this part of the town or better still, did this installation have any significance with the town? Is this military activity and if so, why would a large cave or underground installation be constructed and for what purpose? What would be the necessity of very wide, well paved roads leading throughout this complex? Why the two smaller buildings being covered with earth? What would be the relationship between these two smaller well constructed buildings and the large underground installation? Farther back some

three miles was the very large warehouse type of building and the other hard surfaced road leading from this building to the underground installation some five miles away which stimulated another thought. If this is a military activity, what is it? Would the large airfield observed near Caviarski have any affiliation with this complex of installations, if so to what extent? How about the major artery leading from the airfield to Vodiniski and thence to this wooded area? Why is this linked up with the airfield? Would this be a fuel dump for the airfield, possibly not — it's too far.

(4) These are only a few of the questions which went through the mind of the observer. Remember previously I stated that a good aerial observer must be a good tactician. In order that he is assured of the things he observes as being targets, and further, if these are targets, what significance do they have? What is the relationship with the target observed and its immediate vicinity? To achieve this mental picture I state without further explanation, the visual observer must be a graduate of a photo-image interpretation course.

(5) The visual observer had the answer as to what the activity observed in the wooded area really was. In two minutes after departing from the wooded area, the observer "flashed" the following message to Assistant G2 Air Staff Officer at the Army Airfield — "ENEMY SHORT RANGE MISSILE SITE NEARING COMPLETION IN WOODED AREA, COORDINATES UT916091. TARGET AREA INCLUDES UNDERGROUND LAUNCH SITE AT COORDINATES UT91562045, FINAL CHECK OUT INSTALLATION COMPRISED OF TWO CONCRETE BUILDINGS WITH SOIL OVER THE ROOFS AT COORDINATES UT915830, MISSILE ASSEMBLY BUILDING AT COORDINATES UT923143, AND SUPPORTING AIRFIELD LOCATED AT COORDINATES UT963425 SOUTHWEST OF CAVIARSKI. MISSILE SUPPORT EQUIPMENT INCLUDING THREE PROBABLE LOX TRAILERS, TWO ACID TANK TRUCKS AND SEVEN MISSILE HAULING TRAILERS LOCATED AT EDGE OF WOODS COORDINATES UT915921. THAT IS ALL."

Future Capabilities of Air Visual Surveillance

The future capabilities of visual reconnaissance must meet the requirements for air reconnaissance of the future. Direct and/or remote observation requirements must consist of an observation system capable of locating and describing natural and man-made objects and ground features, with instantaneous transmission of the collected information to the user.

The increased mobility, in conjunction with the increased range in new weapons, dictates a greater reliance on organic aircraft in the future in visual reconnaissance for target acquisition. There is a requirement for a higher performance aircraft in the future to perform Army missions to include the observation and surveillance within hostile territory for the purpose of detection, location, and identification of targets for Army weapons, adjustment, and surveillance of fires, damage assessment, and to include the supplementing or replacing the present Army observation aircraft (L-19) when the enemy has the capability of limiting our use of low performance aircraft in the visual reconnaissance role.

Under developing tactical concepts, increasing emphasis is being placed on accurate and complete reports from observation systems, resulting from a greater necessity for accurate target location and fire detection information and the need for more rapid and accurate battle area intelligence due to the increase in mobility and fire power of units. A more thorough and technical training of visual observers (both inflight and TV or other sensor systems) will afford a more rapid approach to a continuing comparative analysis for target information of enemy areas.

Future development of visual sensory, such as reconnaissance by electronic means (television in aircraft) will provide a means of providing directly to the user, an actual view of the reconnoitered area or target without the delays inherent in photography.

Conclusions

I realize that considerable research has been performed in visual search techniques, and I also fully appreciate that some highly significant data have been determined as result of this extensive research. The mental analysis and deduction of information obtained by the visual aerial observer parallels the mental analysis of photo-imagery interpreters who extrapolate intelligence information from imagery. I reiterate the visual observer must be a graduate of a photo-image interpretation course. It is through this knowledge and techniques and principles of target acquisition that the aerial observer can best accomplish his mission.

In conclusion, although the hypothetical illustration used in this paper may be a trifle unrealistic in some respects, the sequence of events leading up to and following the example are usual. Let us hope that tomorrow our observers are adequately trained in the art of finding what they are looking for, making a mental analysis of the target significance and then reporting the information accurately and expeditiously to the reporting agency. The Commander is waiting for that vital information. Whether he gets this much needed information and whether he receives the information in time to be of value depends essentially on the efforts of his visual surveillance observers.

COAST GUARD PROBLEMS AND TECHNIQUES OF VISUAL SEARCH IN AIR-SEA RESCUE OPERATIONS

ROBERT ADAMSON

Many facets of this subject are common to all of the Armed Forces; therefore, I shall cover briefly our overall situation and emphasize those items peculiar to Coast Guard operations.

The danger and avoidance of mid-air collisions is a matter of serious concern to all of us. The Coast Guard tries to solve the problem in two ways. The first is in strict, flight-crew discipline, requiring all crew members to follow a positive routine in scanning and to be linked by an ICS for immediate communication. Maximum use of the auto pilot is encouraged. The greatest number of eyes of the cockpit crew is available for search. Many other standard practices are followed, which, I am sure, are used by all flight crews. However, in another manner we are taking positive steps to allow early sighting of our own aircraft. Recently the Coast Guard has adopted a high visibility paint scheme, and within the near future we expect to have this coloring applied to every such aircraft in operation. In taking this step, we realize that many improvements can be made, but we considered it essential to put some plan into effect at least as an interim measure. Basically, this design is white with a fluorescent orange trim. Let me say that the Coast Guard is definitely interested in any improvement on this pattern to afford better visibility.

The other field in which visual methods are of great importance to the Coast Guard is in carrying out our primary mission, which is SEARCH AND RESCUE. In 1957 we published our first SEARCH AND RESCUE MANUAL, containing procedures which are now followed by all of our units. In making up this publication, we used all material made available to us from many sources, and I certainly want to emphasize that much information was obtained from the Navy Publication, SEARCH AND RESCUE, NWP-37. However, we did a considerable amount of what we believe to be original work in further development. One section in particular sets forth exact search patterns to be used for various circumstances and a directing method of reporting coverage. In this manner nothing is left to chance, as a search pilot will follow a procedure known to all others in the organization. Two patterns are shown in Figs. 1 and 2. We are particularly sold on

SEARCH AND RESCUE MANUAL

SEARCH PATTERN (PS)

TYPE: PARALLEL TRACK SINGLE UNIT

PURPOSE: For search of an area when position of the target is known only approximately or not at all.

COVERAGE FORMULA:

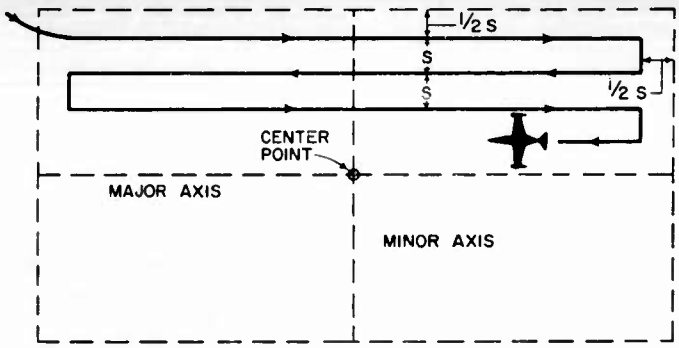
$$S = \frac{A}{nVT}$$ or use Figure 7-25.

PROBABILITY: Use Figure 7-24.

METHOD OF DESIGNATION:
Search Pattern PAPA SIERRA
Center Point ..... North ..... West.
Axis ..... True ..... (Mi) by ..... (Mi).
Creep (direction).

OR

Designate by geographical coordinates.



METHOD OF REPORTING COVERAGE:
Search Pattern PAPA SIERRA
Center Point ..... North ..... West.
Axis ..... True ..... (Mi) by ..... (Mi).
Probability ..... %

OR

Report by geographical coordinates.

SEARCH AND RESCUE MANUAL

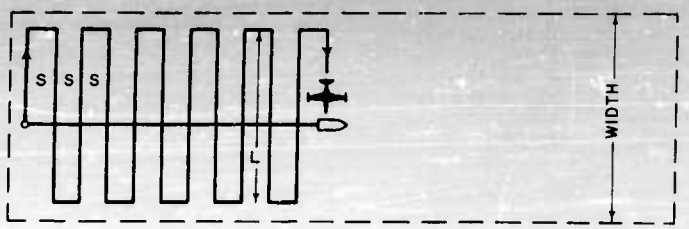
SEARCH PATTERN (CSC)

TYPE: COORDINATING CREEPING LINE SINGLE-UNIT

PURPOSE: For use when distressed unit or survivors are reported between two points, but exact position is not known. For search of a track when distressed unit or survivors may be to either side of track due to navigational error or drift. Provides for accurate navigation and close track spacing.

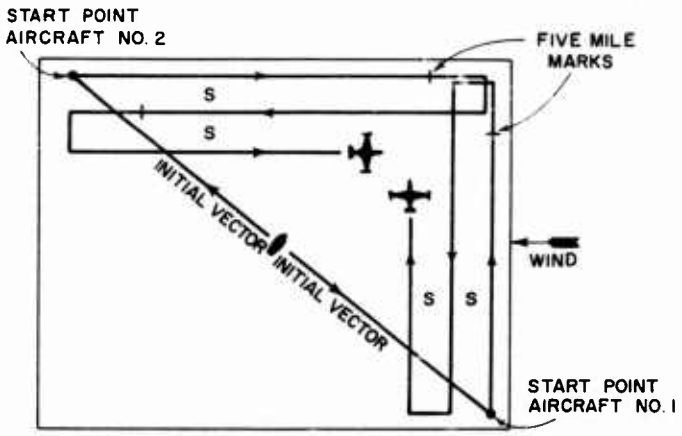
COVERAGE FORMULA: Use Figures 7-26a, b, c, or d.

PROBABILITY: Use Figure 7-24.
METHOD OF DESIGNATION:
*Search Pattern CHARLIE SIERRA CHARLIE
..... North ..... West to ..... North ..... West.
Width ..... miles.
*(Above method of designation used by controlling activity to On-Scene-Commander.)
When a vessel has worked out details of the pattern, it passes to aircraft as follows:
Search Pattern CHARLIE SIERRA CHARLIE.
Ship Course ..... true. Ship speed ..... knots. Track space ..... miles. Length aircraft legs ..... miles. Use speed ..... knots.



METHOD OF REPORTING COVERAGE:
Search Pattern CHARLIE SIERRA CHARLIE
..... N ..... W to ..... N ..... W
Width ..... miles
Probability ..... %

one type of search, and that is the type in which air units are controlled by, or use as a reference point, a surface unit (SEARCH PATTERN SC, see Fig. 3). One of our greatest problems in overwater search has been the difficulty of carrying out precise navigation and thereby guaranteeing effective coverage. In using a ship,



SEARCH AND RESCUE MANUAL

SEARCH PATTERN SC

TYPE: CHECKERBOARD

PURPOSE: For use when target of search is small, and location is known within a radius of about 30 miles, and close track spacing with accurate navigation is required. Two aircraft and one radar equipped vessel are required. Aircraft search on courses perpendicular, and are kept corrected to course by radar advisories from the ship.

COVERAGE:

$$S = \frac{A}{nVT}$$ or use Figure 7-25.

PROBABILITY: Use Figure 7-24. (Second search curve)

METHOD OF DESIGNATION:
To vessel:
Search Pattern SIERRA CHARLIE.
Center point ..... N ..... W
Axis ..... true ..... (mi) by ..... (mi)
OR
Designate by geographical coordinates.

Vessel to Aircraft:
Search Pattern SIERRA CHARLIE
Center point ..... N ..... W
Axis ..... true ..... (mi) by ..... (mi)
Trackspacing ..... miles.
Plane (Buno) search legs (Direction).
Plane (Buno) search legs (Direction).
Stand by for vectors to starting points.

METHOD OF REPORTING COVERAGE:
Search Pattern SIERRA CHARLIE
Center Point ..... North ..... West.
Axis ..... true ..... (mi) by ..... (mi)
Probability ..... %
OR
Report by geographical coordinates.

this problem is virtually eliminated, and in reducing navigation requirements, allows more eyes to be available for active search.

Generally speaking, the Coast Guard feels that our procedures are quite effective when carried out properly. However, once again, we are always anxious to find a still better way.

Another area in which we are definitely weak, and I feel that we have a lot of company in this situation, is in night search. Until a comparatively short time ago, night searches were somewhat futile in most cases. Recently we have made attempts to develop some method of solving this vital problem. For years our only search aid has been the standard parachute flare, producing illumination of 600,000 to 1 million candlepower over a period of 3 minutes. However, this method gives limited illumination of an uncertain quality, covering a very small area. Due to lack of sufficient aircraft and the high cost of dropping flares, this method is suitable for use only when the distress area is reasonably localized. And that brings us to our greatest shortage and greatest need, in our search operations. Coast Guard SAR work involves a great variety of cases in addition to aircraft distress. For example, our Air Station at San Diego, California, is in the midst of a very heavy small boat activity, and at the homeport of a large fishing fleet. On an average weekend as many as 10 distress cases involving yachts, speed boats and fishermen may be handled, and half of these might be handled during the hours of darkness. I can remember personally, too many cases like the one when two brothers were fishing in a small cabin cruiser, which capsized late in the day. They tried to hang on to the overturned hull, but during the night slipped off. In spite of an intensive night search, the bodies were not found until daylight. And yet, we had passed close to them during the night, but simply did not have the equipment to allow sighting.

At present we are attempting to find a piece of illuminating equipment which will be effective for night search. We have investigated some searchlights, and this seems to be the best solution so far, but we are hoping for something better. This piece of equipment must be maintained by average service personnel, be capable of operation continually over a period of hours, and most important of all, must give sufficient illumination. What we would like to know is this. How many foot candles are needed to give adequate illumination during times of total darkness, in locating a passive small object with no ability to attract attention to itself? Once we can arrive at this figure, then it will be easier to decide which piece of equipmen will satisfy our needs.

If I may add a few remarks along non-technical lines, the average flight crewman, who flies over the water day after day, might consider the subject of "Visual Search Techniques" rather a "dry" matter, and indeed it might be if viewed by him through the medium of graphs and formulas. However, his views will be changed radically at the time he finds himseh clinging to a life raft with death the most likely prospect. The subject has suddenly become vital to him. But will he know how to help himself, how to conserve his signalling devices until the proper moment? Or will he fire his flares when the search aircraft is too far away to see them, or when the aircraft is down-sun from him? And just as important, if this man is one day a crewmember of a plane searching for other survivors, will he know how to use his eyes effectively in locating a small object in the vast expanse of the ocean? The only answer to these questions is TRAINING. An efficient, well trained, enthusiastic flight crew is necessary to carry out the most efficiently organized search plan. So once again, we find that when man-made equipment fails, success or failure ultimately depends upon the smoothest operating piece of equipment in the aircraft, if used properly, the human binocular visual system.

VISUAL ASPECTS IN COLLISION AVOIDANCE OF AIR FORCE AIRCRAFT

CHARLES A. BAKER

During the morning daylight hours on 21 April 1958, an Air Force F-100 jet aircraft and United Airlines DC-7 collided at an altitude of about 20,000 feet near Las Vegas. Based on an analysis of the approach angles, the opaque ring on the F-100 canopy would have interfered seriously with the detection of the DC-7. On the DC-7, the corner post between the forward and side windscreen could have interfered with the ability of the airline pilot to see the F-100. Nearly 50 persons received fatal injuries. One month later an Air Force T-33 jet aircraft collided with a Capitol Airline Viscount over Maryland. It is believed that neither pilot saw the other aircraft even though the visibility conditions were good. Only the T-33 pilot survived.

These two accidents, involving commercial passenger carriers, received more national publicity than all of the 650 other mid-air collisions experienced by the Air Force since January of 1947. Since just these few dramatic and tragic instances of mid-air collisions have received such wide publicity, the general public is unaware of the high frequency of such accidents. The following statistics were recently made available in a paper entitled "USAF Mid-Air Collisions," published in November, 1958, by the Air Force Directorate of Flight Safety Research.

1. From January of 1947 to June of 1958 the Air Force has experienced 634 mid-air collisions. Almost one-half of these accidents resulted in at least one fatality.

2. Collisions between military and civilian aircraft are rare. Only 18 such accidents have occurred (two of which were commercial passenger carriers) during the entire history of the Air Force as a separate service.

3. Approximately four out of every five mid-air collisions occur under visual contact conditions during daylight hours.

4. The majority of the mid-air collisions occur within 20 miles of an airdrome.

5. Jet aircraft were involved over five times as frequently in major accidents as were non-jet aircraft.

6. The errors of commission or omission in mid-air collisions indicate that the pilots of jet aircraft perceive the other aircraft either not at all or too late to avoid contact.

Ideally, of course, we would prefer not to rely on the pilot's visual capabilities to avert mid-air collisions. However, until a satisfactory means of accomplishing this is possible, the pilot will have to retain the responsibility for detecting other aircraft in the area and taking any necessary evasive action. It is evident from the number of collisions that do occur that some intermediate measures for decreasing the probability of such accidents must be found. Therefore, the Air Force has initiated a program, the primary aim of which is to effect an

immediate decrease in mid-air collisions. Of interest here is that part of the program which is oriented toward making aircraft more detectable to the pilot.

One technique that has resulted consists of putting a wide band of orange daylight fluorescent paint around the nose section of the aircraft and a similar band around the aft section of the fuselage. The wing tips are also painted (A film was shown of a C-131 and an F-100 painted in this way which indicated how the orange markings appeared against various backgrounds.)

In 1957, the Air Training Command initiated a program aimed at reducing the number of collisions in that command. The measures taken included painting the aircraft with orange fluorescent markings as well as instituting improved ground control techniques. Prior to the adoption of these safety measures, the Air Training Command was experiencing a steady increase in mid-air collisions involving trainer aircraft. In a recent two year period, for example, there were 25 of these accidents in the Air Training Command alone. Nineteen of the accidents were attributed to failure of the pilots to detect each other in time to avert a collision even though visibility conditions were good. After adoption of these safety measures, ATC noted a consistent decline in the overall number of mid-air collisions involving its aircraft. It is interesting to note that the reduction in the collision rate closely follows the progress of the painting project. Statistics covering the first year of the program were recently made available; in that time period, not one painted aircraft was involved in a mid-air collision.

Last summer, a rather simply conceived flight test on the detectability of painted and unpainted aircraft was conducted by WADC. The film shown previously was taken during those tests. Observers were stationed both on the ground and in observation aircraft. Under the limited conditions of the test, the distance at which an aircraft was first detected was shown to be independent of the existence or non-existence of orange fluorescent markings on the aircraft. Both the unpainted and the painted aircraft were clearly visible at distances far greater than those at which it was still possible to discern the presence of the orange markings. However, most observers felt that the painted aircraft were much more conspicuous at nearer distances than were the unpainted aircraft.

At the present time, the Air Force is in the process of applying the orange markings to many of its aircraft. While no figures are available as to the effectiveness of the markings in reducing the number of collisions or near misses, we have had an opportunity to get some "feedback" from the field. In general, most pilots who have volunteered comments feel that the paint contributes to the ease of air to air detection, particularly in landing patterns where traffic density is high. Pilots have also expressed the opinion that the greater conspicuousness of painted aircraft on runways, taxi ramps, and parking ramps substantially eases any trepidations they might have concerning the runway being clear for landing, takeoff, or taxiing. However, there is a minority of pilots which expresses the opinion that the orange paint serves no useful purpose.

Another technique which has been considered as a means of increasing conspicuousness of aircraft is the generation of artificial contrails from aircraft. It is

felt by some that this would increase visual detection range and provide cues as to the aircraft's flight path orientation. This use of colored contrails in low density traffic areas has been recommended to the Federal Aviation Agency for study. However, to my knowledge no studies have yet been performed.

The orange paint and colored contrails, of course, will serve little or no purpose during night operation. To increase the air to air detection range at night, aircraft are equipped with anti-collision lights, in addition to the standard navigation lights. These anti-collision lights consist of a red beam rotating so that the light appears to flash about 90 times per minute.

A flight test program on anti-collision lights has recently been conducted at Wright Air Development Center. The purpose of the test was to determine the relative merits of several anti-collision lighting systems both under daytime and night time conditions. Without going into the details of this study, I would like to summarize the conclusions. One finding was that under daylight conditions the aircraft, orange paint, and in some cases, aircraft insignia were reported to be visible before the lights were visible. It was concluded by the observers that the anti-collision lights used in the flight test served no useful purpose in terms of attention getting qualities under daylight conditions. Under night time conditions, a red rotating beam was concluded to b superior to a white rotating beam even though the white beam was nearly a log unit more intense. The observers reported that the red beam was less easily confused with ground lights and stars. Although the more intense white beams are detectable at greater distances, the greater inte ty was reported to be disturbing to the pilots of the aircraft on which the l s were mounted and to pilots of nearby aircraft. One specific complaint was related to the illumination of the haze or mist in the atmosphere. Another complaint wa t during landing maneuvers, varied illumination of the ground by the rotating beams caused an apparent vertical movement of the ground (or aircraft).

Thus, when an anti-collision light has the most important attention getting quality, that is, intensity, there results a distraction to the crew of that aircraft and crews in nearby aircraft. The overall recommendation of this flight test was to continue using the lower intensity rotating red beam anti-collision light as an Air Force standard.

Another critical aspect of air to air detection relates to the fields of view from inside the aircraft. A program of cockpit visibility was initiated in 1948 by the Civil Aeronautics Authority. The study included: an analysis of questionnaires filled out by airline pilots, film strips to provide a means for measuring cockpit line of sight limits, and in-flight studies of pilot eye movements. Information was gathered on line of sight requirements which would permit pilots to see other aircraft on collision courses. Based on these data and similar studies conducted by the Air Force, design specifications for Air Force aircraft were formulated relating to desired windshield and canopy design. However, few operational combat aircraft in the Air Force are designed in accordance with these desired specifications. The reason for this is that those design features which optimize aerodynamic properties are frequently incompatible with windshield-design characteristics which will maximize visibility. Further, protective clothing worn by the military

pilot restricts head movement and thus further reduces the field of view. As a result, the pilot is able to view conveniently only about 15 per cent of the total visual space about his position. Eighty-five per cent of the space about him is thus unavailable to visual search. Therefore, it must be kept in mind that visual detection, even if perfect within these limits, can provide only a partial solution to the problem of mid-air collisions.

Another important consideration in determining air to air visual detection capabilities is the amount of time the pilot can devote in scanning the areas outside the cockpit. During the takeoff and climb phases of flight, which are usually in high density areas, the pilot spends almost two-thirds of his time monitoring flight and engine instruments. During the landing approach, although the pilot devotes three-fourths of his time looking outside the aircraft, most of this scanning is directed straight ahead in order to maneuver the aircraft into alignment with the runway. Thus a large area is left for the unobserved intrusion by another aircraft.

Several years ago there was much emphasis on an effort to develop an airborne collision warning indicator. The impetus for this effort was primarily the Grand Canyon crash of the two ill-fated commercial airliners. Two different types of systems were proposed. These were the proximity warning indicator and the collision avoidance system. The proximity warning indicator was conceived as a relatively simple sensing and display system that merely warned the pilot that another aircraft was within a certain distance of his aircraft. The collision avoidance system concept is much more complex in that it would analyze an air traffic situation and, when necessary, automatically direct the auto-pilot to make an evasive maneuver to avoid a possible mid-air collision. Although several development efforts on both of these systems are continuing, no device has yet been found which satisfies the requirements of both civil and military aviation agencies.

The proximity warning indicator is of interest to this meeting. The simplest approach merely provides an alerting signal indicating that another aircraft is within some specified distance. With additional electronic complexity, this device could also inform the pilot as to the relative bearing of the other aircraft. It is not known with any certainty whether this additional information will significantly contribute to a reduction in mid-air collisions. Its value would be particularly doubtful in high density areas in which such a warning device might be activated continuously. The long range plans to reduce mid-air collisions call for the development of a national and even global scale automatic Air Traffic Control System. By means of surface radar monitoring or other means, aircraft will be guided through reserved air space. However, it is felt that development and installation of such a system will be years away.

Therefore, even as these guidance techniques are improved and placed in operation, until a fully safe, completely automatic system comes into use, the visual detection capabilities of pilots will continue to play an important role in the prevention of mid-air collisions. It is imperative that we determine as accurately as possible the limits of these visual capabilities, so that man can best be utilized in this system and so that the demands placed on him will not exceed his capabilities.

USE OF BINOCULARS IN SEARCH FOR SUBMARINES

R. P. SMITH

Introduction

The problem of finding submarines at sea is one of the greatest that faces the U. S. Navy today. Despite advances in various electronic and acoustic methods of submarine detection since World War II, visual detection still plays a vital role in search operations. Results of exercises with our own submarines have shown repeatedly that even today a substantial portion of initial detections by aircraft are made by visual means. Although the modern snorkel submarine spends much less time on the surface than its predecessors of World Wars I and II, it nevertheless presents a visible surface target during some portions of its operating cycle. The question under consideration in this paper is the value of binoculars as an aid to airborne visual search for snorkeling submarines under daylight illumination.

OEG has been interested in the field of ocean search problems, including visual search since World War II. Much of the work on visual search was in fact done by Dr. Lamar when he was with the Group. This paper is based on the methodology described in OEG Report 56, 'Search and Screening," published in 1946(1), and some fleet operational data published by the U. S. Navy's Operational Development Force in 1951(2). Reference(1) considered the question of the value of binoculars in airborne search for surfaced submarines and concluded that binoculars are not as effective as the naked eye for this purpose whenever the meteorological visibility is less than about 10 nautical miles. Similarly, reference(2) found operationally that against snorkel targets the use of binoculars resulted in a reduction in search rate, even though greater ranges of detection were sometimes observed. The results of this paper are in agreement with these two sources.

Nature of the Target

The snorkel mast of a submarine is a relatively insignificant target by comparison to its wake. Figure 1, based on data from reference(1), shows the estimated area of the snorkel wake as a function of submarine speed. A representative speed for such a submarine is about 6 knots, yielding a target of about 2,000 sq ft in area. This is appreciably smaller than the wake of a surfaced submarine, estimated at about 13,000 sq ft in reference(1), but is several hundred times greater than the aspect area of the snorkel mast. Following reference(1) the intrinsic contrast, C_o, of the wake is taken to be 50 per cent. This figure is representative of a typical wake in light-to-moderate seas, viewed within 45 degrees of the horizon under unlimited daylight visibility conditions. The apparent contrast at the observer's eye will, of course, depend on the actual visibility and the target range.

Method of Approach

The basic tool of this study is the visual detection lobe for a single "glimpse" as described in reference(1). The field of vision of the eye is taken to be circu-

Fig. 1. Effect of speed on area of snorkel wake.

larly symmetric about the visual axis. Any specified object appearing in this field is seen with a probability that varies with range and angular displacement from the visual axis, among many other factors, but does not depend on the azimuthal angle about this axis. In the visual field, therefore, a family of surfaces of equal detection probability may be described for any particular object, and these surfaces will be surfaces of revolution about the visual axis. Because the search process is probabilistic, no more can be said about the detection of the object than that in a single glimpse it will be seen with a certain probability specified by the particular surface on which it lies. However, for convenience of mathematical description and application, one particular surface of the family is singled out and is assumed to define a detection lobe in a deterministic sense. That is, it is assumed that if the object lies inside this particular surface, its detection is certain, whereas if it be outside, its detection is impossible. It is desired that the surface chosen give results equivalent to those obtained when the entire family of probability surfaces is used. The basis of the equivalence is that in a random distribution of targets, the single deterministic surface must predict the same expected number of detections per glimpse as the more detailed probabilistic model. Actually, a somewhat different surface would be chosen when the targets are distributed in space than when they are distributed on a plane surface or in some other way. However, for this study the choice will be the same as that of reference(1), namely the surface with detection probability of 57 per cent glimpse. This surface is called the visual detection lobe. It will be assumed that the same detection lobe applies to all search tasks involving targets distributed in a plane surface, regardless of the location of this plane relative to the visual axis. It is not believed that the errors arising from this assumption are of appreciable magnitude.

The starting point for the mathematical definition of the detection lobe is an empirical relation derived from optical experiments cited and discussed in detail in reference(1). This relation is shown in Fig. 2 along with a typical detection lobe computed from it.

$$C_t = 1.75\Theta^{\frac{1}{2}} + \frac{19\Theta}{a^2} \qquad (1)$$

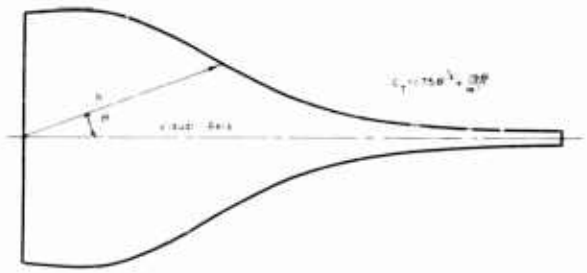


Fig. 2. Typical detection lobe.

This equation specifies the threshold apparent contrast C_t of the target (relative to its background) required to give a detection probability of 57 per cent per glimpse for a circular target located Θ degrees off the visual axis and at a range such that its diameter subtends an angle of a minutes at the eye of the observer. The angle Θ in this equation ranges from 0.8 degrees to about 90 degrees. For values of Θ less than 0.8 degrees, C_t is constant and equal to its value at $\Theta = 0.8$. As pointed out in reference(1), the equation may also be applied within rather wide limits to non-circular targets, provided that a is referred to the diameter of an equivalent circular target subtending the same total solid angle as the asymmetric target. Furthermore, either Θ or a may also be regarded as a threshold value required to assure 57 per cent sighting probability when the other two variables are fixed. It will be observed that equation (1) defines the detection lobe described previously. The size, range, and orientation of the target determine the angle a. Its direction in space, coupled with a specified direction of the observer's visual axis, determine Θ. Meteorological visibility and the intrinsic contrast of the target, which depends on its physical character, determine C_t. The various combinations of these variables which satisfy equation (1) thus mark out, for any specified target under specific circumstances, a region in space within which the sighting probability per glimpse is equal to or greater than 57 per cent. By the reasoning of paragraph 1, this region is the visual detection lobe for the specified target and circumstances. Equation (1), on which this entire study depends, is essentially empirical and is subject to the usual uncertainties about such simple correlations. Possibly better data have been obtained since reference(1) was published. However, it is believed to be sufficiently accurate for

the purpose of this study, which is to compare the use of binoculars with the unaided eye rather than to assess either one in an absolute sense.

The use of binoculars will, of course, greatly alter the character of the detection lobe. The method of approach in this study is to investigate the geometry of the detection lobe for a variety of targets and search circumstances, with and without binoculars. The effects of binoculars on certain geometric properties of the detection lobe will then provide a basis for assessing the merits of their use in various situations. It should be noted that this procedure does not consider a number of secondary factors which can also influence the assessment of binoculars. Some of these are: (1) reduction of light intensity by reflection or absorption by the lenses, (2) magnification of vibrational disturbances in the visual field, especially in aircraft, (3) difficulties in handling and in change of search direction, (4) increased strain on the observer.

Such factors have in fact been noted in reference(2). Also not considered here is the important possibility of joint use of binoculars and the unaided eye in the same search task, either by employment of several observers or by dividing the time of the same observer between the two types of effort. Finally, no attempt has been made in this study to extend the simple geometric results to operational performance criteria, such as sweep widths or lateral range curves, as was done in reference(1). In principle this extension would not be difficult to do, though it would be necessary to make a number of assumptions about the nature of the search scanning process and about the meaning of the term "glimpse." It is not felt that such an extension would lead to any conclusion different from those obtainable from the geometric results alone, at least insofar as assessment of binoculars is concerned.

Characteristics of the Navy Mark 41 Binoculars

The relevant characteristics of binoculars for the present study are the magnification power, M, and the limiting half-angle of the visual field, β. For the Navy Mark 41 binoculars, M is equal to 7. Strictly interpreted, this means that the angle subtended at the eye by any linear dimension of an object seen though the binoculars is increased by a factor of 7 relative to its value as seen by the unaided eye. In this study it will be taken to mean that all linear dimensions of the object are apparently increased by 7, or equivalently that the object is apparently located at $\frac{1}{7}$ of its actual range from the observer. The aspect area of the object, and the solid angle subtended by the object at the eye, will thus be increased by 49.

The visual field of the Navy Mark 41 binoculars, referred to real space, is about 10° wide. In this study it will be assumed that the limiting half-angle of the field of vision, β, is 5°. Objects located more than 5° away from the visual axis cannot be seen through the binoculars.

It is assumed in this study that the quality of the lenses in the Navy Mark 41 binoculars is such that their use entails no loss in resolving power or light intensity relative to the unaided eye. With equipment in good condition, neither of these losses should be significant. It is further assumed that no losses in search

effectiveness occur as a result of unsteady handling, vibration, or observer strain. These factors can be assessed only by experience.

Measures of Search Effectiveness

A very simple measure of effectiveness for comparison of binoculars with the unaided eye is the area of ocean surface searched per glimpse. This area may be measured from a calculation of the plane section of the detection lobe cut by the ocean surface. When the observer is on or near the surface and is looking toward the horizon, this area is simply the section through the visual axis. In other cases, a somewhat more complex calculation is necessary. This measure of effectiveness is applicable to search in which glimpses are made in a series of random directions or at random intervals, i.e., when overlapping of searched areas does not detract significantly from the cumulative detection probability.

If search is performed from a moving vehicle and the observer's visual axis is held in a fixed direction, a more relevant measure of effectiveness is the total scanned length of ocean surface in the direction normal to the motion of the vehicle. This length, multiplied by the speed of motion, measures the area swept out per unit of time. If the direction of motion relative to the observer's visual axis is specified, this length is easily obtained from the plane section of the detection lobe. When searching for inert or friendly targets such as life rafts, the optimum search procedure is to search directly abeam, as this direction assures the maximum scanned length. However, an unfriendly snorkeling submarine will submerge completely if it sights the aircraft and may thus avoid being detected. For this reason it is desirable to sacrifice some search capability abeam by directing a portion of the search effort in the forward direction so as to increase the chance of sighting the target before the aircraft is sighted by the target.

General Formulation of Detection Lobe Equations

From the geometry of the search situation, taking into account the increasing obliquity of the wake target as the range increases and the effects of meteorological visibility on apparent target contrast, it can be shown that the basic detection lobe equation takes the form:

$$C_0 e^{-3.44\frac{R}{V}} = 1.75\Theta^{\frac{1}{2}} + 28.4\frac{\Theta R^3}{Ah} \qquad (2)$$

where

R = target range in n miles

V = meteorological visibility in n miles

A = actual target area in square feet

h = observer altitude in feet

and C_0 and Θ are as defined before. An important special case of this equation occurs at the foveal limit of $\Theta = 0.8$ degrees, corresponding to maximum range of target detection, R_m. For a value of $C_0 = 50$ per cent, solutions to this equation are shown in Fig. 3 as a function of $(Ah)^{\frac{1}{3}}$ for various values of V. This figure shows

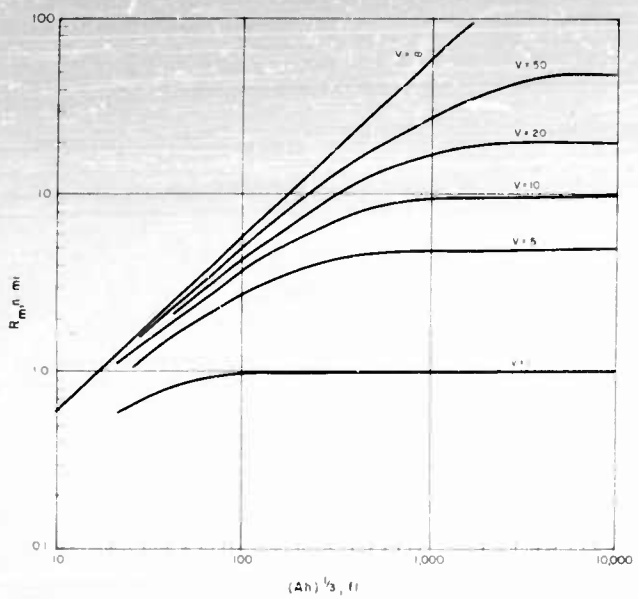


Fig. 3. Effect of visibility on maximum detection range.

that for sufficiently small targets under conditions of sufficiently high visibility, R_m increases as the $\frac{1}{3}$-power of the target area or the observer's altitude. At fixed altitude, this conclusion is equivalent to the statement that R_m increases as the $\frac{2}{3}$-power of the magnifying power of any visual aids used, such as binoculars. Of course the altitude of the observer must be sufficient to enable the full realization of this gain short of the horizon limit. For moderate to large values of target area and observer altitude, magnification will increase the maximum detection range by a factor less than the $\frac{2}{3}$-power of the magnification. When the visibility is sufficiently low, the increase in maximum range may be negligible.

For any specified conditions of visibility, target area, and observer altitude, equation(2) specifies the formula for the detection lobe of the unaided eye. To determine the detection lobe in the case of binocular search, the same equation may be used after appropriate allowance is made for the optical effects of the binoculars. The first of these effects is of course the apparent increase in target area. For the Navy 7×50 binoculars, the increase is a factor of 49 corresponding to an increase in $(Ah)^{\frac{1}{3}}$ by a factor of 3.66 and an increase in R_m by a factor somewhat less than this depending on the visibility. The second effect is an apparent increase in the angle Θ between the target image and the visual axis, as observed at the eye of the observer. This effect may keep the target image outside the detection lobe even though the apparent area of the target image is increased. Finally, the limiting 10-degree cone of the field of view of the binoculars cuts off

the detection lobe beyond about 5 degrees from the visual axis in real space, or about 31 degrees in image space.

Results

The results of these detection lobe calculations are shown in Fig. 4. For each of three values of visibility, cross-sections through the axis of the detection lobe

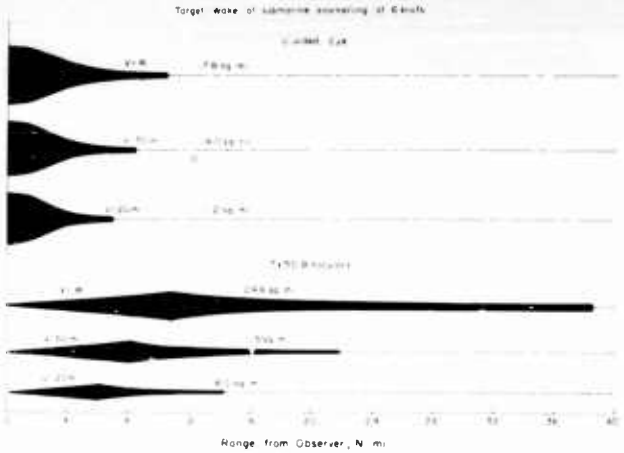


Fig. 4. Cross sections of detection lobes through visual axis.

are shown for the unaided eye and for 7 × 50 binoculars in the search for the wake of a submarine snorkeling at about 6 knots and the observer at an altitude of 3000 ft. These are drawn to the scale indicated.

In actual search operations, the aircraft will be at some altitude so that the detection lobe does not intersect the ocean surface along the visual axis. Standard search doctrine calls for an altitude not greater than 600 ft per n. mile of maximum range, so as to permit a reasonably large area of intersection of the lobe with the ocean surface. Figure 5 shows the area of intersection when the aircraft flies at an altitude of 3000 feet and the observer directs his sight at the expected maximum detection range, which is recommended for search by the unaided eye in reference(1). In all three cases, the 3000 ft altitude is well below the doctrinal ceiling. You will note that the search area for the unaided eye is only very slightly affected, whereas the binocular search area is substantially reduced and in two cases appears to be broken into pieces. This latter effect is a consequence of the assumed shape and deterministic character of the detection lobe, coupled with the requirement that the observer direct his sight at maximum range. More refined data on the character of the detection lobe are necessary to determine whether this effect is a genuine one. In any case, it could be eliminated either by adopting a lower search altitude or by having the observer direct his sight at a

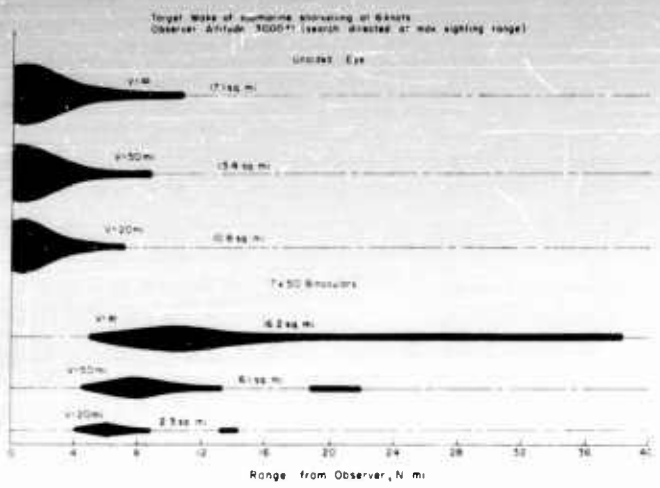


Fig. 5. Sections of detection lobes on ocean surface.

range less than the maximum range. Some improvement both in the area of intersection and in the length of the scanning line could thereby be obtained though, in the case of reduced altitude, as a sacrifice in maximum range of detection in accordance with Fig. 3. This sacrifice would also have to be accepted for the unaided-eye search in such an event.

Table 1 shows a tabulation of these results in condensed form. In terms of search area per glimpse, the use of binoculars is seen to offer no advantage under

TABLE 1

SUMMARY OF RESULTS

Target: 6 knot snorkel wake (2000 sq ft), viewed from 3000 ft altitude

Unaided Eye			
	V=00	V=50	V=20
Search Area per Glimpse, sq mi	17.1	13.4	10.8
R_m, n mi	10.5	8.5	7.0
Scanned Length, n mi	10.5	8.5	7.0
7 x 50 Binocular Search			
	V=00	V=50	V=20
Search Area per Glimpse, sq mi	16.2	6.1	2.3
R_m, n mi	38.6	22.0	14.4
Scanned Length, n mi	33.7	12.4	6.0

any conditions of visibility. In terms of scanned length, binoculars are advantageous only when the meteorological visibility exceeds 20 nautical miles, which

constitutes unusually favorable conditions in the North Atlantic. Only in terms of maximum range of sighting does the use of binoculars appear to offer any advantage.

Finally, Table 2 shows some operational data reported in reference(2). $(R_m)_N$ and $(R_m)_B$ are the maximum observed ranges of detection for the unaided eye and

TABLE 2

OpDevFor Data

Altitude, ft	$(R_m)_N$	$(R_m)_B$	W_N	W_B
1500	7.7	10.2	11.0	9.3
3000	9.4	10.8	14.0	11.0
5000	11.4	14.4	18.0	15.5

7×50 binoculars respectively, and W_N and W_B are the operational sweep-widths obtained. The target was a snorkeling U. S. submarine and the aircraft altitude varied from 1500 to 5000 ft as indicated. The data were not obtained under homogeneous conditions of sea state and meteorological visibility, but these conditions were generally described as favorable. In accordance with theory, in all three cases the maximum detection ranges were higher in the case of binocular search than with the naked eye, but the operational sweep widths were smaller. From the R_m data, it would appear that the data were taken under conditions such that the meteorological visibility was about 15 miles.

The conclusion to be drawn from these results is that under all but the highest visibilities, the use of binoculars is disadvantageous in airborne search for snorkeling submarines under daylight conditions. When it is recalled that no account has been taken in this study of such factors as the increased effects of vibration and observer fatigue associated with binocular usage, this conclusion is further strengthened. However, because of the increased maximum detection range possible, binoculars can still be a valuable aid in identifying suspicious targets detected by the unaided eye or other means. Furthermore, when a large amount of search effort is available, tending to saturate the nearer ranges of possible target positions, it may be profitable to assign one or two observers to binocular search at ranges in excess of the unaided-eye capability. In practical operations, however, the likelihood of such a wealth of search effort is remote.

REFERENCES

1. OEG Report 56, Search and Screening, Chapter IV, 1946.
2. OpDevFor Final Report on Project Op/V60/16-3(17), 24 July 1951.

PROBLEMS OF VISUAL SEARCH IN THE RECOVERY OF SPACE VEHICLES

MYRON A. FISCHL

The purpose of this presentation is to describe some of our visual search operational experiences in the recovery of space vehicles. The objects of search were basketball-size capsules and larger vehicles. Some of the dimensions of the search task were that the vehicles were primarily afloat at sea, would have to be searched through an illumination range covering night with no moon through night with full moon to the high level of bright sunlight. Additional limiting factors in the search task were cloud coverages and discriminability from wave whitecaps. The search angles through which the object had to be viewed were both large (search from aircraft at approximately 10,000 feet) and small (search from surface craft).

Several steps were taken in increasing the detectability of these vehicles. For color contrast the vehicle itself was painted International Orange. When experience showed this color to be attractive to marauding fish, the portion of the vehicle which would be submerged was painted black. In addition to increasing color contrast, the effective target size was increased by employing a fluorescein dye marker. This is a fatty acid treated aluminum powder of relatively low solubility. Under ideal conditions it would create an omni-directional slick and would cover an area of approximately 2,000 feet around the vehicle. Depending upon surface winds and local currents this slick was found to cover an area as small as 300 feet and, at worst, its form became that of a narrow trailing ribbon rather than an omni-directional slick. Brightness contrast for night search was increased by employing a small white light of 75-100 lumens, the common pilot light. A further step was to increase the attention getting quality of the light by raising the intensity and by programming intermittence into the stimulus. To this end we employed a Xenon light of 250 μsec pulse length, one flash per second pulse rate, and 1×10^6 lumens peak output (and a newer light of the same size but with 12×10^6 lumens peak output). Other search aids considered and/or tried were smoke bombs and daisy flares.

Personnel conducting the search were reasonably heterogeneous in background. They included General Electric development engineers, and Navy and Air Force crews both trained and untrained in search procedures. Since visual fatigue has been known to set in fairly rapidly, and many hours could be consumed in search before sighting the target, every attempt was made to rotate observers after 30 to 60 minutes of search and to provide a 30 minute rest period. This rotation of personnel required carrying an excess number of people so as to provide for continuous search. For search from shipboard this presented no staffing problem, sufficient personnel were available; but for search from aircraft, it was not always possible to provide for the supernumerary person for purposes of rotation. Where sufficient personnel were available they were assigned sectors for their search and were instructed to scan through about 20° to 40°, with head as well as eye movement. They scanned roughly 10° per second, but of course

this varied with the speed of the carrier (aircraft vs. surface craft). Other than these few protocols no one prescribed scanning pattern was employed. Sunvisors and sunglasses were provided for use in daytime search and there was slight use of magnification aids (approximately 7 power). These binoculars were not continuously used since in prior study binoculars had been found to restrict the field of view and to be fatiguing to the eyes. They were employed for identification rather than search purposes.

Field Test Experiences

Observers reported that after 30 to 60 minutes of search they experienced extreme tiring of the eyes, and "after about an hour you don't see anything." Their performance following this 30 to 60 minute search period was characterized by inconsistency, i.e., overlapping of ranges, which appeared to be greater than merely the effect of individual differences. The results of some of our steps toward effecting various contrasts were that the fluorescein dye when acted upon by ocean currents and surface winds yielded the narrow ribbon-like target described earlier, even when omni-directional in form, the discrimination of this gray-white slick from wisps of clouds still created perceptual difficulties. Chemists may be attempting to introduce color to this slick. An initial problem of the aluminum powder splashing on the radio-antenna and short circuiting was corrected through development of a different type of antenna, which remained internal to the vehicle. We do not necessarily believe that our lights were of optimal settings, but size, weight, and power consumption must be restricted to allowable physical tolerances.

Flares were considered because of the high intensity of output, however, two mitigating conditions precluded their extensive use. The first was the short exposure time of existing flares, the second was the risk of a flare going into the parachute canopy if parachute descent were employed. Smoke was considered and was employed in early work; however, there was again the relatively short exposure time in the current state-of-the-art, and weight and space requirements for automatic triggering imposed rather severe limitations. Glare problems were encountered during daytime search. The most severe and obvious of these was imposed by the reflection of the sun off the water, and the discrimination of this from the sun off the aluminum slick.

Future Directions

In order to increase the probability of detection through visual search, definitive research in the following areas is needed.

1. Since a capability for recovery irrespective of impact area is desirable, determination of the effect on thresholds and parameters of visual search in snowy areas, in wooded areas, in mountainous terrain as well as at sea seems necessary.

2. Research workers should be trying to pin down and quantify the effects of various magnification aids. Are they of any use in visual search? Are they

purely for identification, and not to be used for search? To what extent is there specificity of magnification aid for the various aspects of the search and recovery task?

3. Research workers would want to pursue a course of definitive studies over a fairly extensive range of intensities, flash rates, and flash durations for various types of lights. This work should be organized so as to provide trade-off information against size, weight, and other physical limitations.

4. These research workers intend to document further the work on conspicuity of smoke. Such factors as colors, densities, exposure times, and methods of triggering must be considered.

5. We should like to see further definitive work in the psychophysiology of the visual mechanism in search tasks. This should lead to alternative methods for visual search, each with statements of the probability of detection.

6. Also on the personnel, as opposed to hardware, side of the ledger we believe that once search methods have been treated a little more fully, programs of visual training may yield great dividends in maximizing the probability of detection.

7. Finally, a comprehensive study of individual differences may provide clues leading toward a program of selection. It is not unlikely that some people may perform consistently better than others in a visual search situation and the development of protocols for identifying these individuals would appear to be time well spent.

STIMULUS RELATIONS AND METHODS OF VISUAL SEARCH*

HILDA R. BRODY, H. H. CORBIN, and JOHN VOLKMANN

The task is to describe briefly two experimental situations, and to state the principal results. One situation deals with *horizon search*, and the other with *search in a rectangular matrix*.

To simulate the conditions of horizon-search a large-scale psychophysical cyclorama installed in an old gymnasium was used. This apparatus presents to the subject a one-dimensional *Ganzfeld* that covers 160° on a 30-foot radius. It consists of a semicircular wooden frame, 5 ft high, covered by a seamless piece of white sheeting 85 ft long. The scene is dimly and nearly uniformly illuminated by one 25-watt lamp placed high above the geometrical center of the cyclorama. The stimuli are ¼ in spots of orange light produced by small neon lamps; the spots appear 2 in above the floor (or "horizon line") at any desired azimuth. The subject views the display from a hooded booth located at its center. She can see the entire arc of the screen, including its ends, and part of the floor; that is all, because her view of the top of the screen, the room over the screen, and her own body is occluded. In the dim illumination, the screen has no visible microstructure, hence it offers no anchoring stimuli except at the two ends. Anchoring stimuli, when desired, were provided by hanging weighted black tapes down over the front of the screen.

A control apparatus, located in an adjoining room, programmed the stimuli and presented them automatically. The stimuli were coded into letters of the alphabet, and their order was then punched into a tape. The chief components of the apparatus were as follows: a timer, a tape-transmitter, a relay-tree, a relay-bank with one relay for each stimulus-position. The apparatus as a whole permitted control and variation of the following principal independent variables, within wide limits: the brightness of the stimuli, the angular range within which they appeared, their temporal order, and their duration. An accessory timing apparatus, mentioned below, provided auditory stimuli to pace the subject's searching behavior in certain of our experiments.

In responding, the subject raised her hand quickly under her chin and pointed directly at the stimulus-spot. The onset of stimulation started a stop-clock, and the subject's response stopped it. So one of the principal measures was the latency of detecting a lasting stimulus. The other measure was the frequency with which a brief, non-lasting stimulus was detected at all.

These are the main stimulus relations that our experiments have turned up: first, the search time varies directly with the angular range over which the subject must search. This relation appears to be linear. Secondly, search time varies inversely with the brightness of the stimuli, though we did not determine the precise form of this relation. These experiments imposed no special method of search upon the subject.

*This research is sponsored by the Operational Applications Laboratory, Air Force Cambridge Research Center, Air Research and Development Command, U.S.A.F.

Next is a special dependent variable: the angular range within which detection is rapid. This range varies with target brightness. In one experiment, head-movement was eliminated by using a biting board, and eye-movement was minimized by using instructions for fixation, a fixation mark in the center of the cyclorama, and short exposure-time (1/10 sec). The results show that at the high brightness levels the brief stimuli could be seen anywhere within 160° (see Fig. 1). At the middle brightness the effective range has decreased to about 70°, and

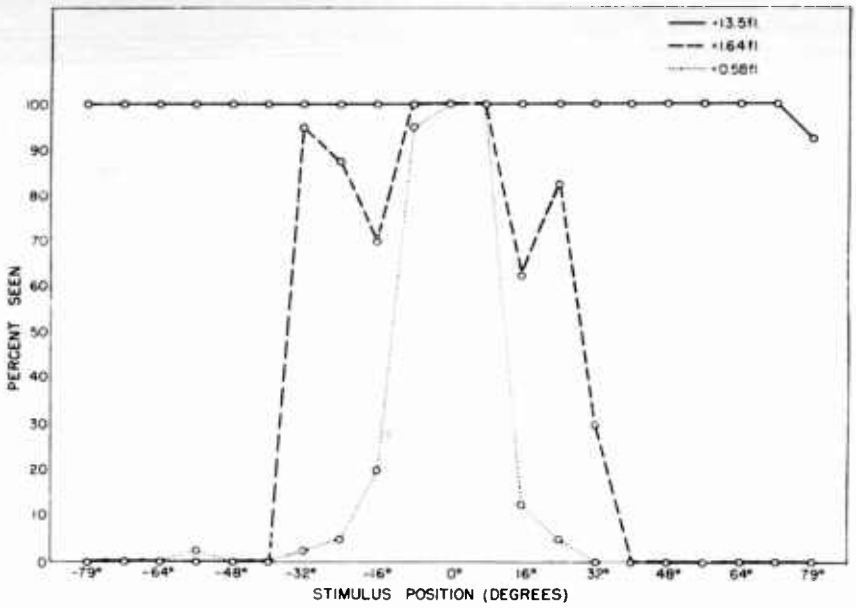


Fig. 1. The per cent of brief stimuli seen as a function of stimulus position in degrees. As a parameter, three levels of stimulus brightness in foot-lamberts. Data of one subject, B.G.

at the low brightness to only 15°. The curve for the middle brightness shows clearly the effect of the blind spot at 16° right and left of the fixation point; although the stimulation was binocular, a stimulus falling on the blind spot of one eye was occasionally missed completely.

Under different experimental conditions, when both eye and head movements were permitted, some brief stimuli were not seen even at high brightness. In ordinary language, the subject was looking somewhere else. She began by fixating in the middle of the cyclorama; when the *ready* signal came, she first searched to one side and then to the other. To find the next stimulus following, she began the search on the alternate side. The stimuli were brief (1/10 sec). Under these conditions, the angular range, within which virtually all of the stimuli were seen, shrank to 90°, even at high brightness. At lower brightnesses, many stimuli were missed at all locations.

If this result is compared with the previous one (in which there was no substantial head or eye movement) it may be seen that in a sense the best search is no search at all. Searching behavior produces misses as well as discoveries. Unfortunately, the stimulus conditions (and other conditions) frequently make a search necessary.

Much of the research in the Mount Holyoke laboratory has been concentrated on methods of search. Imagine a subject in the cyclorama searching from side to side for the small stimuli. She can see each end of the cyclorama, and 4 black tapes that mark off equal fractions of the total arc. Her search is paced with a set of auxiliary auditory stimuli: a click of a telegraph sounder to mark the time of fixation at each of the 4 tapes, a bell to mark it at one end of the cyclorama, and an electrical clacker to mark it at the other. So the subject sweeps the cyclorama from one end to the other and back, keeping in position with the pacing system. Except at the highest searching rates, this is actually not at all difficult to do.

The foregoing conditions we call paced search. The experiments also included pseudo-continuous search: only fixation at the ends is marked by auditory stimuli. The subject sweeps the intervening space "continuously," although her eyes do not actually move that way.

In the experiments as a whole, the rate of pacing was varied to give times of 25 sec to 1.25 sec per cycle. It was possible to predict the general form of the results from some simple assumptions: that the subject stays on pace; that she sees the stimulus the first time that she sweeps over it; that the stimulus-locations are randomized with respect to the place that the subject is fixating. This randomizing was in fact secured by the design of the experiment. The curves of predicted search time show longer times for stimuli at the ends of the cyclorama, and longer times for the slower search rates.

Figure 2 shows that these two effects really occur. Curves of group median search time have been plotted for two rates of search: 25.0 sec and 5.0 sec per cycle, and for the two search-methods: paced and pseudo-continuous. The datum-points also show the effect of intermediate fixations in the paced method of search; the times are shorter for stimuli near the fixation-tapes. The paced method shows no net advantage over the pseudo-continuous method, however. Fast rates are much better than slow ones, but there is an optimal rate of search (about 5.0 sec per cycle, under our experimental conditions). The rate of 2.5 sec per cycle gave longer search times, and the rate of 1.25 was really poor. Apparently the subject could not follow the fast pacing and still discover the stimuli quickly. The finding of an optimal rate of search may have some importance for military reconnaissance practice, although it is likely that the optimum rate will vary considerably with the situation and the task of search.

Now to describe the second experimental situation, in which the subject searched for a particular symbol within a rectangular matrix of symbols.* In the principal experiment she looked for a single solid black triangle in a matrix other-

*These experiments were conducted by Miss Jacqueline A. Carter.

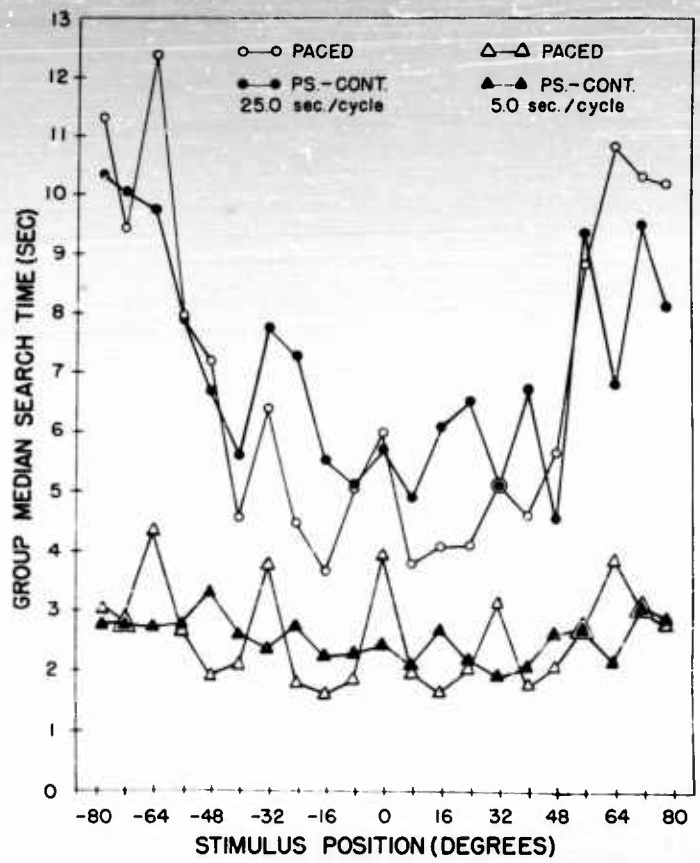


Fig. 2. Group median search time in seconds as a function of stimulus position in degrees. One parameter is the rate of search in seconds for one complete search cycle. The other parameter is the method of search: paced or pseudo-continuous.

wise composed of solid black circles. The symbols were printed on white paper by special characters on an IBM typewriter. An opaque projector displayed the matrix on a screen 5 ft 7 in. square, located 9.5 ft in front of the subject. A timer opened an electrically operated shutter and started a stop-clock; when the subject found the triangle she immediately pointed at it, struck a glass plate and by electronic means stopped the clock. The dependent variable in the experiment was the familiar latency of search in seconds.

It was desired to make the critical stimulus (the triangle) stand out like a sore thumb under some conditions, and get lost like a needle in a haystack under

others. This can be done within the framework of the same experiment, merely by varying the total number of symbols in the matrix. This total number was varied from 2 to 3600 in 32 steps. The area of the matrix grew correspondingly. The position of the critical stimulus was systematically randomized over the area of the matrix. Six subjects provided data adequate for individual graphical analyses.

The overall relation between search-time and matrix size is nearly linear, as Anderson and Green(1) have found in a similar experimental situation. The curves in the present study display a slight positive acceleration. The data are most probably heterogeneous, however, in the sense that the subject's behavior appears to be different for large matrices, medium ones, and small ones. In looking for the triangle in a large matrix, she "read" the matrix according to some system; different subjects apparently used different systems. Considering matrices of medium size, we suspect that the search begins at the center, then wanders around it. Smaller matrices form another separate case, as will be seen below. This heterogeneity of search method implies that no single, highly specific mathematical model can be expected to describe the entire relation between search-time and matrix size.

Most interesting of all is what happens at the smaller matrix sizes. Look at Fig. 3, and search for the triangle. — There is, in effect, no search at all; the tri-

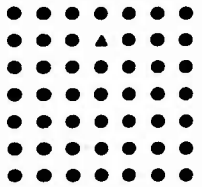


Fig. 3. A sample matrix, containing 7 x 7 symbols. To illustrate the rapid appearance of the critical symbol, a black triangle, in a matrix of less than the critical matrix size.

angle peps out at you from the matrix. Figure 4 presents the data at the lower matrix sizes for one subject. Above a matrix size of 100 the data show a small first-order discontinuity. The measures of variability likewise increase in this region. There is a third evidence of a critical matrix size near 100; it concerns the time required to find a triangle located in the center of the matrix. Since the subjects fixate the apparent center of the screen before the exposure, they do not have to search at all for this particular triangle. So this time serves as a kind of basal time; it is constant above 100 for this subject. The search-times for larger matrices as a whole therefore diverge upward from this basal time at about 100.

In general terms, there is apparently a *critical matrix size* (cms), below which there is no search at all; above which there is wandering or systematic search. For this subject and these stimuli the cms lies between 100 and 144. The data of the other subjects had the same form; the cms was found in the same region of the function, though not always in the same specific place. Different combinations of symbols have been found to produce very different values of the cms. It should be noted that the median search-time increases up to the cms, as Fig. 4 shows.

These are the findings so far. They call for a whole series of further experiments. For example, the cms might be expected to decrease as the critical symbol

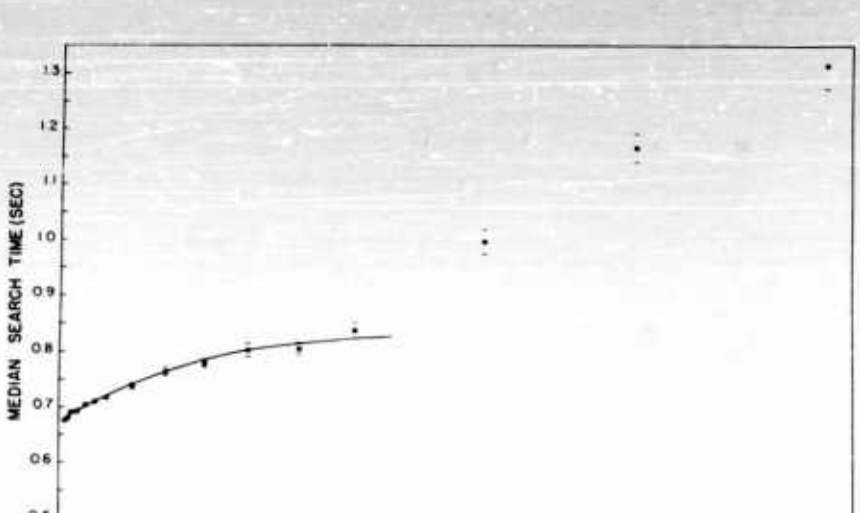


Fig. 4. Median search time in seconds as a function of matrix size. To indicate the reliability of the data one $Q/\sqrt{N}$ has been plotted above, and one below, each median. The critical matrix size lies between 100 and 144. Data of one subject, C.S.

and the background symbols became more alike. It should be possible to find a cms even though the background symbols are not homogeneous; the cms may vary with the degree of homogeneity. The finding of the cms might depend merely on a spatial threshold for recognizing the critical symbol in indirect vision; we must be able to show that this is not so: that the cms depends on the competitive action of the background symbols. Finally, to be very useful, the cms should be invariant when certain obvious variables of viewing are changed within reasonable limits. These are the variables of matrix shape, matrix density, viewing distance and angular size of the matrix.

The cms may have both theoretical and practical significance. Theoretically, it may represent an informational limit on the read-out from a single visual fixation. Practically, it could provide us with a measure of coding effectiveness. The ideal visual display would contain only those symbols that can be used below their critical matrix sizes. Whatever the operator looks for, it is there — and without his taking a second look.

REFERENCES

1. Green, B. F., and Anderson, Lois K. Color coding in a visual search task. *J. exp. Psychol.*, 1956, **51**, 19-24.

SEARCH DISTRIBUTIONS IN MAGNIFIED TIME*

WILLIAM J. McGILL

Tiny differences are characteristically hard to measure, and the hazards of trying to work with them are no less frustrating in visual perception than elsewhere. Accordingly there is something particularly appealing about a technique, even a statistical one, that aims at magnifying small perceptual differences instead of merely testing them for significance.

We have in mind a relatively simple visual problem and a rather specific statistical scheme for amplifying small differences. One of its major advantages is that most of the statistics seem to be inside the organism. These subjective statistics impart at least one surprising property to the data.

Consider the following experiment. A subject is told to find an object located at random among many similar objects. All objects are put in front of him and he searches until he finds the right one. There are many versions of the basic situation(1, 2, 4, 5), but, to be specific, let us suppose the object is a three-digit number and the background alternatives are other three-digit numbers. The subject must find the proper number, and we record how long it takes. As soon as he finds it, the numbers are rerandomized, a new target number is substituted and the procedure is repeated until a distribution of search times builds up. The purpose of this paper is to describe the changes that take place in the distribution of search times as the number of alternatives is changed.

Empirical Distributions

Figure 1 presents data from a typical search experiment. The four distributions shown were obtained with 24, 48, 72, and 96 alternatives. The plotted values are the 10th to the 90th decile points of each distribution, and they give the probability that the target number is not yet found by time t. The smooth curves in Fig. 1 are based on a probability model that will be discussed shortly. However, the amplifying scheme does not depend in any way on the choice of a model.

In this example the alternatives were small, three-digit numbers chosen and located randomly on an 18-inch white square. The target numbers were selected with uniform probability from the alternatives on each square. All this randomizing turns out to be necessary in order to wash out local effects due to peculiar configurations of alternatives. Four different randomizations were constructed for each number of alternatives, making a total of sixteen stimulus cards which the subjects viewed in random order.

The subjects were 25 female graduate students at Teachers' College. Each S made one search on each of the sixteen stimulus cards. The four sets of 25 search times for each number of alternatives were then inspected, checked for homogeneity, and pooled into a single distribution. The result is that there are 100 pieces of data in each distribution in Fig. 1.

*Willing and able assistance given by Mary Norrie is hereby gratefully acknowledged.

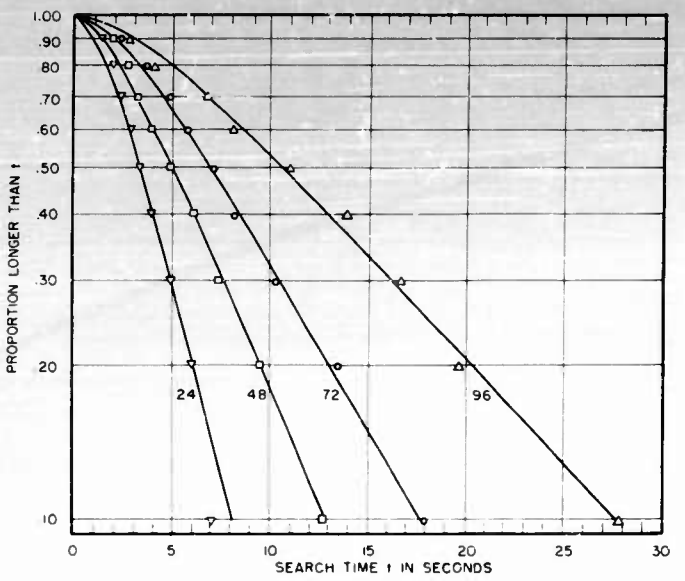


Fig. 1. Distributions of 100 search times for one of 24, 48, 72, and 96 three-digit numbers randomly arranged on a small white square. The decile points of each distribution are compared with probabilities computed from equation (4) in the text.

The property of the distributions that we have advertised as surprising in earlier paragraphs is this: all four distributions can be very nearly superimposed by an appropriate scale factor multiplied against the time axis. In other words, an increase in the number of alternatives is equivalent to expanding time by a constant multipher. This feature of the data is shown in Fig. 2 in which the distribution of search times for 48 alternatives is compared with equivalent decile points for 72 alternatives. The relation is seen to be approximately linear. Similar approximately linear functions can be demonstrated for any combination of the four distribution curves so that it becomes unnecessary to plot them all.

Apparently there is really only one search distribution. Its changing appearance is due to a time parameter that is fixed by the number of alternatives. Consequently the discriminative properties of the target in relation to its background can be represented by any or all of the observed distributions. Furthermore a line connecting equal probability points in the four distributions traces out various time magnifications of this discriminative difference. To be more accurate, we should speak of the changes in search time as *demagnifications* when the number of alternatives increases, since the target object becomes harder to find. However, as soon as we compare two slightly different objects by searching for one and then the other against the same background, it is easy to convert the per-

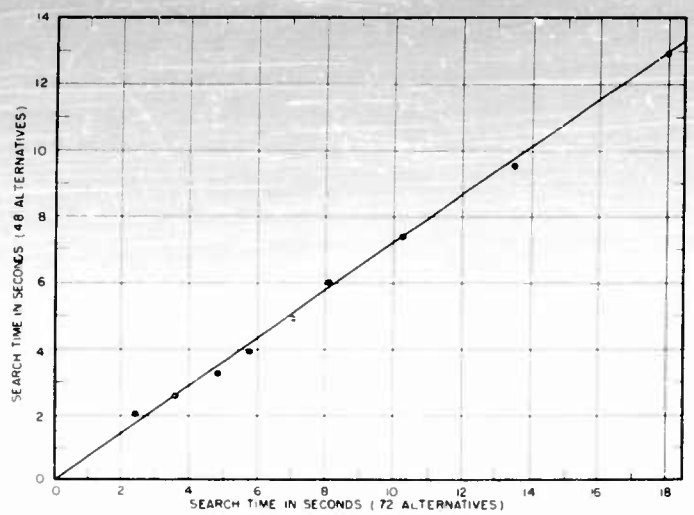


Fig. 2. Empirical linear relation between search times for one of 48 alternatives, and search times for one of 72 alternatives.

ceptual difference between them into a difference between search times, and the latter can be amplified. For example, suppose that the target number had had only two digits instead of three. This target would probably have been more visible against the background, and, as a result, it would have traced out an entirely different curve against the number of alternatives. Accordingly the discriminative difference between a two-digit target and one with three digits can be measured in terms of a difference in search times, and then arbitrarily magnified by manipulating the number of alternatives.

The Search Model

The curvature in the empirical search functions at low probability is real. It is caused by the fact that the density functions do not fall away exponentially at the shortest search times. The curves start at $f(t)=0$ and then pass through a maximum that moves away from the origin as the number of alternatives increases.

It is dangerous to try to construct a model of searching without saying a good deal about how the subjects do it, but let us make a first approximation in the following way. Suppose that the search process has two components, both of which are random delays. Call the first delay a reaction time and label it r. The second delay will involve active searching and will be identified as s. Our notion is that t, the observed search time, is formed by summing r and s, where both quantities are assumed to be exponentials. We have

$$t = r + s$$

$$f(r) = \beta e^{-\beta r}, \tag{1}$$

$$f(s) = \alpha e^{-\alpha s}. \tag{2}$$

Since the delay due to searching is generally longer than the reaction time, we have an additional condition, namely

$$\beta > \alpha$$

Our first problem is to find the distribution of t. This is easily done and the required density function turns out to be

$$f(t) = \frac{\alpha\beta}{\beta - \alpha}[e^{-\alpha t} - e^{-\beta t}]. \tag{3}$$

Equation (3) is the convolution of s and r. Although the assumptions are crude, this equation seems to have many of the properties of the search data. Its cumulative form is found by integrating f(t) from zero to t:

$$1 - F(t) = \frac{1}{\beta - \alpha}[\beta e^{-\alpha t} - \alpha e^{-\beta t}]. \tag{4}$$

Equation (4) is, in fact, the distribution curve plotted in Fig. 1.

Now let us turn to a more realistic model. In viewing the test field the subject is restricted by his limited attention span. But his attention is not so limited that he must examine the alternatives one by one. What seems to happen is that he divides the test field into small regions and examines each region more or less as a whole. If the target is not in the first region searched, S's eyes move to an adjacent region and search it. He proceeds in this way, skipping around the test field, until the object is found.

It is possible to think of the time required to search a small region as a random variable that has the same distribution in every region of the test field. But the number of regions searched is also a random variable. Hence the distribution of s is compound (3), and varies its form, depending on the number of regions searched. Let $1 - \Theta$ be the probability that the object is in a particular region. Then the probability that it is in the $k+1^{th}$ region searched is

$$(1 - \Theta)\,\Theta^k$$

Moreover, suppose that the time required to complete the search of each region has a density function given by

$$\lambda e^{-\lambda s}.$$

When the object is in the $k+1^{th}$ region searched, the total time spent searching all $k+1$ regions is given by the convolution of $\lambda e^{-\lambda s}$ with itself k times. This turns out to be a gamma variate,

$$\lambda^{k+1}\frac{s^k}{k!}e^{-\lambda s}.$$

The expression for f(s) is found by taking a weighted average over all possible regional searches, i.e.,

$$f(s) = \sum_{K=0}^{K=\infty}(1 - \Theta)\,\Theta^k\left[\lambda^{k+1}\frac{s^k}{k!}\,e^{-\lambda s}\right],$$

$$f(s) = \lambda(1 - \Theta)\,e^{-\lambda(1-\Theta)s} \tag{5}$$

Now if we take

$$\lambda(1-\Theta)=\alpha \tag{6}$$

we find after substituting in equation (5) that

$$f(s)=\alpha e^{-\alpha s}.$$

This is identical with the initial conception of f(s) in equation (2). It is a pleasant surprise to find that a somewhat better approximation of the mechanics of the search process does not materially complicate the model.

Elastic Time

Substitution in equation (4) reveals that a change in parameters is equivalent to a scale multiplication of the time axis, if the ratio of the new parameters is the same as the ratio of the original parameters. For example, suppose that the new parameters are α' and β'. The restriction is

$$\frac{\alpha'}{\beta'}=\frac{\alpha}{\beta}$$

In this event

$$\alpha'=m\alpha$$
$$\beta'=m\beta$$

where m is some constant.

Now consider the search function with transformed parameters α' and β':

$$1-F(t)=\frac{1}{\beta'-\alpha'}\left[\beta' e^{-\alpha' t}-\alpha' e^{-\beta' t}\right],$$
$$1-F(t)=\frac{1}{\beta-\alpha}\left[\beta e^{-m\alpha t}-\alpha e^{-m\beta t}\right],$$
$$1-F(t)=1-F(mt),$$

where the parameters in F(mt) are α and β. Thus when the search times in the original distributions (parameters α, β) are compared with those in the transformed distribution (parameters α', β') at equal probability points, the comparison yields a straight line having a slope equal to m.

We can illustrate the comparison by referring to the search data presented earlier. The estimates of α and β for 48 and 72 alternatives respectively are

$$\alpha_{48}=.20, \qquad \beta_{48}=.70,$$
$$\alpha_{72}=.15, \qquad \beta_{72}=.50.$$

In this instance m is somewhere between .71 and .75. The slope of the straight line in Fig. 2 is .72.

The elastic time property indicates that the ratio of the parameters remains fixed despite changes in the number of alternatives. This indication is borne out in the data, as will be shown in the next section. The constant ratio also makes it clear that the β parameter is not attributable to a simple delayed response. Its relation to the number of alternatives seems to suggest some sort of preliminary search.

Estimating the Parameters

The mean value of the search function described by equation (3) is relatively easy to calculate. It is

$$\mu = \frac{1}{\alpha} + \frac{1}{\beta}. \tag{7}$$

In view of this, one might expect that the sample mean,

$$\bar{t} = \frac{1}{N} \sum_i t_i, \tag{8}$$

would estimate the two parameters in combination. The t_i in equation (8) are sample search times and N is the total number of measurements. This conjecture turns out to be correct, and the maximum likelihood estimator for μ [equation (7)] is $\bar{t}$.

Estimating the parameters individually is much more of a problem. The estimation equations appear to be difficult to solve. However, there is an easy graphical procedure that works fairly well.

To carry out the graphical estimation, we first take the log of equation (4).

$$\log (1-F) = -\log\left(1-\frac{\alpha}{\beta}\right) - \alpha t + \log\left[1-\frac{\alpha}{\beta}\, e^{-(\beta-\alpha)t}\right].$$

The ratio $\frac{\alpha}{\beta}$ is roughly constant in view of the elastic-time property. Moreover, it is fairly small. Accordingly, we get an approximation to log (1 − F),

$$\log (1-F) \simeq \frac{\alpha}{\beta} - \alpha t - \frac{\alpha}{\beta}\, e^{-(\beta-\alpha)t}.$$

As t increases, the last term on the right goes out very quickly and produces a second approximation for large t,

$$\log (1-F) \simeq -\alpha\left(t-\frac{1}{\beta}\right). \tag{9}$$

Equation (9) is entirely plausible if we think of the reaction delay r as an initial pulse that decays quickly in the relatively long time spent searching. The approximation treats f(r) as though all its probability were concentrated at the expected value, $\frac{1}{\beta}$. Hence equation (9) is simply an exponential distribution displaced from the origin by a constant. The observed distribution of search times can then be plotted on semi-log coordinates and a line can be fitted to the trend of the points at the longer search times. The slope of the line is $-\alpha$, and its intercept constant is $\frac{1}{\beta}$.

Values of α and β obtained in this way are given in Table 1. The same constants were used to fit the four curves in Fig. 1. In addition Table 1 shows the ratio of the parameters which, as suggested earlier, appears to be approximately independent of the number of alternatives.

TABLE 1

ESTIMATED VALUES OF SEARCH FUNCTION PARAMETERS

Parameters	Number of Alternatives			
	24	48	72	96
α	.34	.20	.15	.095
β	.95	.70	.50	.33
α/β	.36	.29	.30	.29

As noted at the beginning of this section, the parameters enter into the expected value of the search function [see equation (7)]. It also happens that the sample mean search time, $\bar{t}$, is the maximum likelihood estimator of equation (7). In view of this, the adequacy of the graphic procedure can be checked by substituting the parameters estimated in Table 1 into equation (7), and comparing the estimates so obtained with the sample mean search times. The comparison is carried out in Fig. 3. On the whole, the estimation appears to be fairly good, al-

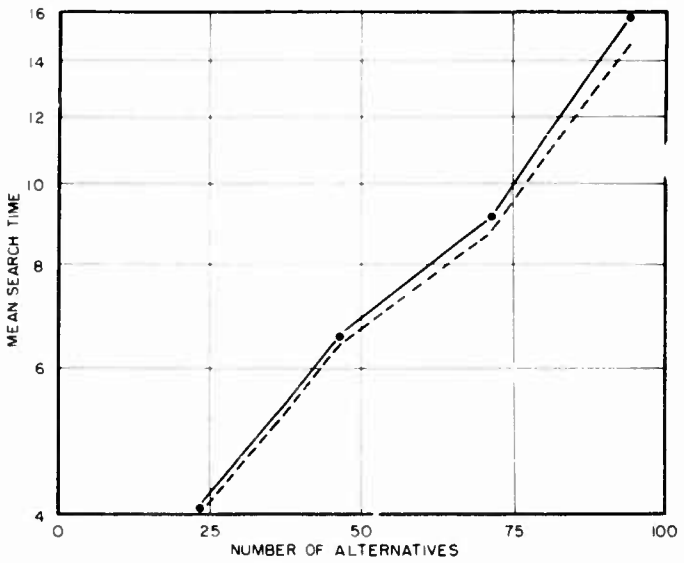


Fig. 3. Mean search times computed from data and compared with estimates derived from parameters. The heavy line connects computed means (open circles), and the dashed line connects estimates obtained from parameters.

though the estimates derived from Table 1 consistently undershoot the mean search times. The linear relation between log mean search time and number of alternatives is strictly empirical as far as the present analysis is concerned.

Discussion

The magnified (or demagnified) discriminative difference between target number and background is traced out by the curve in Fig. 3. The effect is probably due to the statistics of perceptual data processing, probably as a direct consequence of the searcher's limited attention span. Obviously, no real gain in perception is achieved by changing the number of alternatives, for the standard deviation of the search times is multiplied by the same scale factor that amplifies the mean(4). Despite this, the measured difference between target and background can be made to take on any one of a fairly wide range of magnitudes, and this fact can prove useful to someone who wishes to demonstrate the reality of a small perceptual difference experimentally rather than statistically.

Of course, if the perceptual difference between search object and background alternatives is made too small, all search times tend to be long and nothing can be determined conclusively. On the other hand, if two objects that differ minutely are employed, first one and then the other against a common set of background alternatives, the mean search time curves should diverge as the number of alternatives increases. This would be a genuine amplification of a weak perceptual difference.

Putting the scheme in these terms makes it clear that the experiment described in this paper is a poor choice for the stated purpose. Ideally the background should be homogeneous. Randomized digits are homogeneous in some abstract, statistical sense, but not perceptually. Moreover, in the simplest case the target object should differ from the background in perhaps a single dimension. It would be hard to say exactly how a target random number differs from other random numbers.

Now that the amplification effect is understood it is easy to think of better perceptual materials. For example, we are currently experimenting with a background consisting of many one-inch lines oriented at random. The target object, in one instance, is a line $\frac{7}{8}$ inch long and we are trying to find out whether it is discriminably different from a line $\frac{8}{8}$ inch long, by magnifying the difference.

Apart from finding interesting effects to study, there is also the important problem of analyzing what we might loosely call the mechanism of attention. An object that is clearly visible among, say, five alternatives disappears into the background when the number of alternatives is raised to 25. With a good working model it is possible to track the process of the disappearance and to learn how the subject works to discover the object. For example, there is a suggestion in the behavior of the β parameter in these data, that what we take to be a single search may really be a series of searches repeated cyclically, where, on successive cycles, S is tuned to perceive sucessively smaller differences. He looks first at all the objects. If nothing stands out, S narrows his "attention" to small regions and searches them. Presumably if this fails, he narrows his attention again and tunes up for really minute differences, examining objects two by two.

In any case the indicated relation between attention span and difference sensitivity is one of several problems that can be easily and even profitably studied

in terms of the parameters of this model of the search process, or, as seems more likely, in terms of a better model.

REFERENCES

1. Boynton, R., and Bush, W. R. Recognition of forms against a complex background. *J. Opt. Soc. Amer.*, 1956, **46**, 758-767.
2. Eriksen, C. W. Object location in a complex perceptual field. *J. exp. Psychol.*, 1953, **45**, 126-132.
3. Feller, W. *An introduction to probability theory and its applications.* New York: Wiley, 1950.
4. Green, B. F., McGill, W. J., and Jenkins, H. M. The time required to search for numbers on large visual displays. *MIT, Lincoln Lab. Tech. Rep.* August 18, 1953, No. 36.
5. Green, B. F., and Anderson, Lois K. Color coding in a visual search task. *J. exp. Psychol.*, 1956, **51**, 19-24.

THE IDEAL SENSOR SYSTEM AS APPROACHED THROUGH STATISTICAL DECISION THEORY AND THE THEORY OF SIGNAL DETECTABILITY

W. P. TANNER, JR. and R. CLARK JONES

The purpose of this paper is to present an analysis of sensory experiments, identifying the relevant variables, and to present an analysis of those conditions in the environment which place limits on performance in visual experiments. The first will be done by presenting a general model of an ideal observer applicable to any search problem. The second is done by studying the statistical properties of the visual environment.

General Model of an Ideal Observer

The model presented is purely a mathematical concept describing the maximum possible correlation between observable events in very simple detection experiments. These are the stimulus and response events. The model is based on probability theory, which is in turn a mathematical model describing the relation between events in environments exhibiting stable statistical properties. Environments of this type are not frequently encountered in the normal course of events. They may, however, be approximated in experiments.

The model, describing optimum performance, again is unlikely to represent anything which actually exists. An understanding of the model may assist in interpreting data with reference to real observers, either human or engineered, performing in similar environments. The conclusion of the paper will consist of some suggested techniques for using the model as a tool for developing a descriptive model of an observer being studied.

The basis for the model may be illustrated in terms of some simple games of chance. One wins in a simple game of chance whenever the event that he bets on actually occurs. The strategy in such games is always to follow the betting strategy which yields the highest expected value. If there is set up a simple game of chance based on the roll of a die which has four faces each showing a three, and two each showing a zero, and if two dollars to one must be bet if the three is bet upon, and three dollars to four if the zero is bet upon, then the strategy of always betting on the three should be followed. This is based on the following inequality:

$$\frac{0.67}{0.33} > \frac{4+2}{1+3}$$

where the left-hand side of the inequality is the ratio of the probability of the three showing to the probability of the zero showing. The numerator contains the gain and the loss for correct and incorrect bets when the zero shows. The denominator contains the same values for those cases wherein the three shows.

Let the game now be changed to include three dice. One is the die of the previous example, the other two are normal, the faces numbered one to six. The three

dice are now rolled, and the bettor is told the total of the three dice. Based only on the knowledge of the total, he must now bet upon whether a three or a zero on the third die contributed to the total, with the same odds as those in the previous example.

Let be considered now the strategy one should follow when the three dice total seven. Two thirds of the time a three will show. A total of four is required on the other two dice, and this total will occur $\frac{3}{36}$ of the time. The product of the two is $\frac{1}{18}$, the probability that the roll will contain a three and total seven. One third of the time a zero will show, and a total of seven is required on the other dice. Two dice will total seven $\frac{6}{36}$ of the time. Again the product is $\frac{1}{18}$, the probability that the roll will contain a zero and total seven.

Of all the rolls, $\frac{1}{6}$ of the time a seven will be the total. Of these, one half will contain threes and one half zeros. Thus, when the total is seven the inequality

$$\frac{0.5}{0.5} < \frac{4+2}{1+3}$$

determines the strategy, and the bet should be that a zero is included in the total. Each total can be analyzed in the same way. The knowledge of the total moves the bettor from one game of chance to another, the exact nature of which is determined by the total.

The left-hand member of the inequality is the ratio of the *a posteriori* probabilities. This ratio can be written:

$$\frac{P_x(3)}{P_x(0)} = \frac{P(3)}{P(0)} \quad \frac{P_3(x)}{P_0(x)}$$

where x represents the total and a subscript represents a condition on the hypothesis. The ratio on the left represents the information upon which the bet is placed, conditional upon the operation. The first ratio to the right of the equal sign is the information upon which the bet is placed before the roll of the dice. The other ratio is the likelihood ratio which represents the information contained in the observation. It is the likelihood ratio which moves the observer from the *a priori* game of chance to the *a posteriori* game of chance.

The dice game contains the same fundamental operations that are required of an ideal observer in a sensory experiment. Such an observer is illustrated in the block diagram of Fig. 1. The sensory input (in the dice game, the total of the three dice) is fed into the likelihood-ratio computer. The output of the likelihood-ratio computer is fed into the decision computer, which maps the value into a criterion space (either that set of totals leading to the strategy of betting on three, or that set leading to the strategy of betting on zero). This mapping completely determines the decision.

At this point it becomes obvious that for this observer to perform the operations specified there is considerable information required. In order to compute a likelihood ratio it is necessary to know the likelihood of the input conditional upon each of the hypotheses to be tested. In a simple detection experiment these

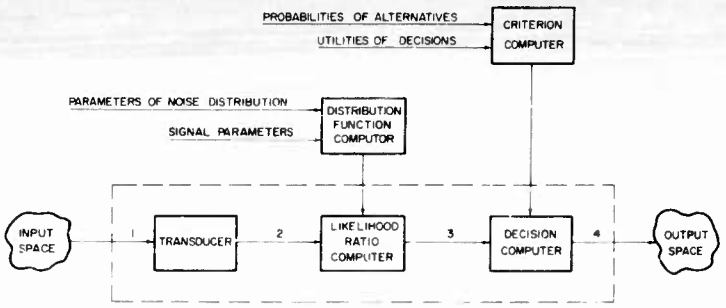


Fig. 1. Block diagram of ideal observer.

distributions are: (1) the probability-density distribution given that noise alone exists; and (2) the probability-density distribution given that signal-plus-noise exists. These distributions are determined by the distribution computer.

In turn, for the distribution computer to do its work, it is necessary to have available the information about the signal parameters (the size of the number on the non-zero faces in the dice game) and of the noise parameters (the fact that there were two normal dice). The ideal observer is specific to the particular task it undertakes to perform. If the experiment is changed, then the ideal observer changes accordingly.

Again, for the decision computer to perform its task the criteria need be known. To compute the criteria one needs the *a priori* probabilities of the signal (the number of faces showing a three) and the function to be optimized (expected value in the dice game). Any change in the experiment involving these factors changes the form of the observer. The specificity of the ideal observer to the task it undertakes is also apparent at this stage.

The ideal observer is perfect in that it utilizes all the information available at the input. It is not perfect in that it must, in a yes-no type experiment, accept both types of errors. How many of these errors must be accepted depends on the separation between the two statistical hypotheses, the probability densities of the inputs given noise alone and signal-plus-noise. Since the ideal observer uses all the information, the separation for it represents a limit imposed on performance by the environmental conditions. It is now time to turn to the problem of determining the maximum possible separation of the parameters as a function of the relevant physical parameters of the visual environment.

Upper Limit of Performance on a Specific Visual Task

The general principles of the preceding section are used in this section to derive an upper limit to the detecting ability of a "flash-perception" detector, and to describe a quantitative measure of the degree to which any actual device, physical or biological, falls short of the upper limit.

The detecting device looks at a flat surface of uniform luminance, B. At an epoch of time, a part, P, of the surface of area a is increased in luminance by the amount B_s for a period of duration T. All these parameters are fed into the detecting device so that they are "known" to the device.

In order to introduce an unknown element as a problem for the device to resolve, the task is extended in the following manner. Instead of just one epoch, there are G epochs equally spaced in time, and the luminance of the part P is increased at one and only one of the epochs. The serial number of the epoch at which the signal occurs is denoted by g, $1 \leqq g \leqq G$.

In a series of *random* trials, the position, g, of the signal is randomly chosen for each trial in such a way that the positions are equally likely; then the *a priori* probability of any given value of g is just 1/G. At each of the trials the device uses some criterion to judge the epoch g at which the luminance is increased. The performance of the device is measured by the fraction, f, of the random trials in which the epoch of the signal is correctly judged.

In the random trials described above, the device receives only one sample in each trial. The method of presenting the signals may be chosen differently, however. Suppose that after a random choice of the epoch g is made, the trial is repeated n times with the same value of g. In such a case, the series of n trials is considered to be just one trial in which the device is presented with n samples. The number n is called the size of the sample.

Now calculated is the signal-to-noise ratio at the input of the detecting device for a series of trials with one sample per trial ($n = 1$).

The part P subtends the solid angle ω at the entrance pupil of the detecting device. The area of the entrance pupil is A. Then the number of photons that enter the detecting device from the part P during the period T when the signal is not present is

$$\overline{M}_b = F\omega ABT/\pi, \tag{1}$$

and when the signal is present the number of entering photons is greater than $\overline{M}_b$ by the amount

$$\overline{M}_s = F\omega AB_sT/\pi, \tag{2}$$

where F is the number of photons in a lumen-second of the light, and where B and B_s are supposed to be expressed in lambert-type units, whence the factor $1/\pi$ in the expressions.

The photon numbers $\overline{M}_b$ and $\overline{M}_s$ are not the numbers that pertain to any one period of duration T, but are, rather, the numbers averaged over a large number of such periods, as indicated by the bars over the letters. The symbols M_b and M_s are used without the bars to indicate the numbers of photons in any given period.

Now inquiry is made about the statistical distribution of these numbers, and more particularly about the mean-square deviation of the number from the mean number. The mean-square fluctuation of the number M_b is defined by

$$N^2 = \langle (M_b - \overline{M}_b)^2 \rangle_{Av} \tag{3}$$

with a corresponding relation for M_s.

The fluctuations in a beam of photons from a thermal source of radiation (and all sources of light are thermal sources) have been studied by Lewis(1), who finds that the fluctuation abbreviated above by N is given by

$$N^2 = \overline{M}_b/(1-e^{-h\nu/kT}) \tag{4}$$

where $h\nu$ is the energy of a single photon, and T, here, is the thermodynamic temperature (in degrees Kelvin) of the radiation. For visible light of any reasonable radiation temperature, the ratio $h\nu/kT$ is large compared with unity, whence the above expression reduces to

$$N^2 = \overline{M}_b. \tag{5}$$

This expression may be derived directly by assuming that the arrival times of the individual photons are random. Fry(2) shows that if the events in a series of discrete events occur "collectively and individually at random," the distribution of the number that occur in non-overlapping periods, each of the same duration, is a Poisson distribution. It is a well-known property of the Poisson distribution that the mean-square fluctuation of the number is equal to the mean number, from which fact the last relation follows.

The number N is the root-mean-square fluctuation in the number of background photons. The corresponding number, S, of signal photons is $\overline{M}_s$. Thus the signal-to-noise ratio is

$$\left(\frac{S}{N}\right)_{rad} = \frac{\overline{M}_s}{\overline{M}_b^{1/2}}. \tag{6}$$

(It is assumed explicitly that $\overline{M}_s$ is small compared with $\overline{M}_b$ so that substantially all of the fluctuation is the fluctuation in M_b.)

The subscript "rad" indicates that this is the signal-to-noise ratio of the radiation incident on the entrance pupil of the detecting device. And if the detecting device makes equally effective use of each of the incident photons, this is the signal-to-noise ratio available to the decision-making element of the device.

The signal-to-noise ratio required by the discriminating element depends on the performance that is specified. Suppose, for example, that the discrimination element is required to detect correctly the epoch of the signal in 62.5 per cent of the trials, and the device is forced to make a choice in each of the trials. If the number, G, of the epochs is four, for example, the calculations of Birdsall and Peterson indicate that a signal-to-noise ratio of 1.22 is required for this performance. (Their calculations are based on the assumption that the distribution is Gaussian, whereas it has been seen by the authors that the distribution is Poisson. If the number $\overline{M}_b$ is large compared with unity, however, the two distributions are practically indistinguishable.)

Now an ideal detecting device is defined as a detecting device that makes equally effective use of each of the photons that is incident on its entrance pupil. It is a corollary that the signal-to-noise ratio available at the discriminating element of an ideal device is equal to the signal-to-noise ratio in the incident radiation. The quantity k is defined as the signal-to-noise ratio required by the ideal detecting device to deliver a specified performance.

Any actual, imperfect device will require a higher signal-to-noise ratio in the incident radiation. In particular, let $(S/N)_{rad}$ be the signal-to-noise ratio in the incident radiation that is required by the actual device in order that it be able to deliver the specified performance. Then the *detective quantum efficiency*, Q, of the actual device is defined by

$$Q = k^2/(S/N)^2_{rad} = k^2 \bar{M}_b/\bar{M}_s^2. \tag{7}$$

It follows that the detective quantum efficiency of the ideal detecting device is unity.

Consider a detecting device that is ideal except for its making equal and effective use of only a fraction, U, of the incident photons. Then it may be shown that the detective quantum efficiency of this device is equal to U. It is this fact that justifies the term detective quantum efficiency. Also, it should be noted that the definition(7) must involve the ratio of the *squares* of the signal-to-noise ratios in order for this property to hold.

Beginning with the paragraph that includes Eq. 1, this discussion has assumed that each trial provides only one sample (n=1). If the trial contains n samples, the signal-to-noise ratio is increased by the factor $n^{\frac{1}{2}}$.

$$\left(\frac{S}{N}\right)_n = n^{1/2}\left(\frac{S}{N}\right)_1 \tag{8}$$

If a detecting device has the signal-to-noise ratio $(S/N)_{rad,\ n=1}$ in a simple sample of the radiation at its input, and if its detective quantum efficiency is Q, the figure of performance d′ defined by Tanner and Birdsall(3) is given by

$$d' = Q^{1/2} n^{1/2} (S/N)_{rad,\ n=1}. \tag{9}$$

Jones has studied the detective quantum efficiencies of a substantial number of different kinds of radiation detectors(4). In particular, the detective quantum efficiency of human vision has been studied by a number of writers(5-9).

The block diagram of Fig. 2 illustrates four experimental channels, C_{11}, C_{12}, C_{21}, and C_{22}, the subscripts referring to the switch positions. The transmitter

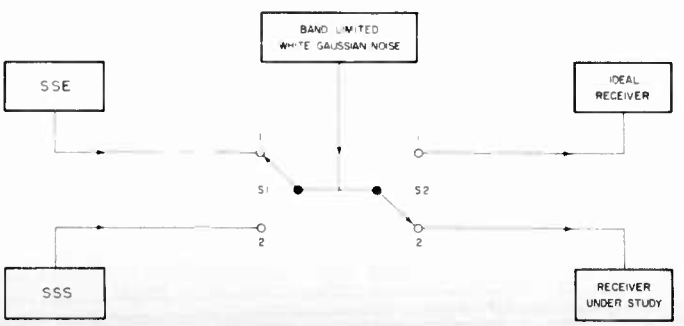


Fig. 2. Composite block diagram of channels for psychophysical experiment.

labeled SSE is one which transmits a visual signal in an exact location at an exactly specified time. As we have seen, the signal is not coherent and thus is similar to an auditory signal which is a sample of Gaussian noise rather than an auditory signal specified exactly. When the channel C_{11} is employed, the receiver is ideal. It observes only the specified location at the specified time. It observes all of the relevant area and time, and no irrelevant area or time.

When the transmitter labeled SSS is employed the signal is specified statistically. For example, it may appear anywhere within a specified area or anywhere in a specified time interval. If the channel C_{21} is employed, the receiver is one which optimizes its observation procedure in accordance with the exact degree of statistical uncertainty in the specification of the signal.

Suppose now that an experiment is performed employing the channel $C_{i,j}$ with i referring to the position of the first switch and j to the position of the second. In this experiment, the signal is specified by $n^{i}\frac{S_{i,j}}{N}$. The performance is measured in terms of a detection rate and a false alarm rate. Then a second experiment employing the channel C_{11} is performed. This is actually a mathematical calculation. The area, duration, and background* level are the same as in the previous experiment. S, however, is attenuated until the performance exactly matches that of the previous experiment. The quantum efficiency is defined by the expression

$$Q=\left(\frac{S_{11}}{S_{i,j}}\right)^{2},$$

and the measure of performance by

$$d'=Q^{1/2}n^{1/2}\frac{S_{i,j}}{N}$$

The measure d' is thus that value of n^{i} S/N necessary to match the performance obtained in the experiment if the channel C_{11} were employed.

The efficiency of the channel can decrease either because the transmitter does not specify the signal precisely, because the receiver is nonideal, or because of both. The extent to which the transmitter leads to a reduction in efficiency depends on the degree of uncertainty. This depends on such things as the area and duration of the signal, and the size of the area and time interval over which it might occur.

From the receiver's standpoint, reduction in efficiency can evolve from the fact that the receiver is noisy, or from the fact that the receiver has imperfect memory and must treat the signal as one specified statistically even though it is specified exactly at the transmitter. Both the noise and imperfect memory can be stated as a degree of uncertainty in the same way as the statistical uncertainty of the transmitted signal. This leads to the following theorem:

> If in two experiments involving the channels C_{21} and C_{12}, each employing the same value of n^{i} S/N, the same quantum efficiencies are found to apply, then the receiver in the channel C_{12} introduces through internal noise

*n is linearly related to the product of the signal area and signal duration.

and faulty memory the same degree of statistical uncertainty as the transmitter in C_{21}.

In order to illustrate the use of this theorem, some calculations have been carried out showing the performance of ideal receivers for signals specified with different degrees of statistical uncertainty. In Fig. 3 the ordinate of the graph is

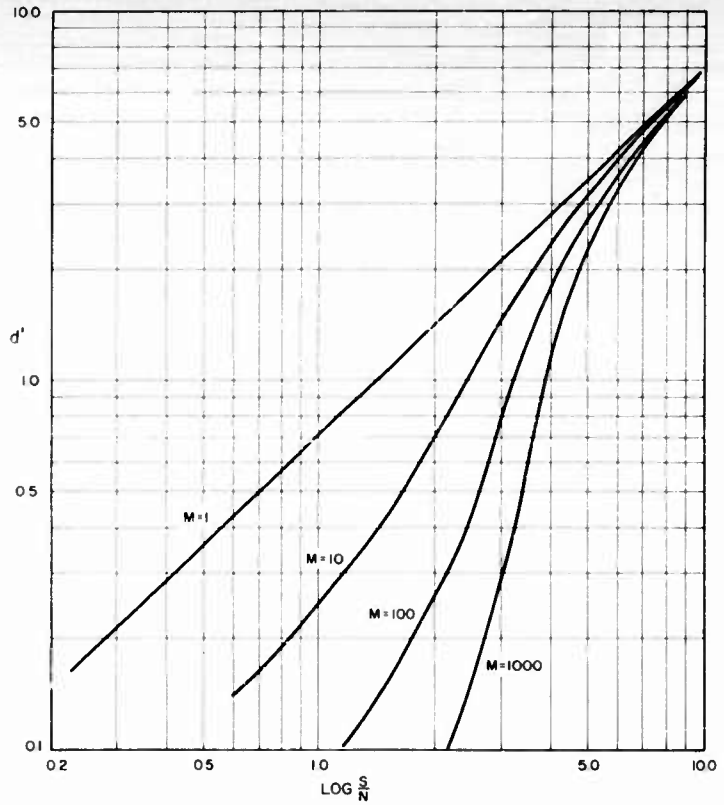


Fig. 3. The detectability of statistically-known signals.

d', the abscissa is $n^{\frac{1}{2}}$ S/N. The parameter on the curve is the degree of statistical uncertainty.

The curve for M = 1 is the curve based on Eq. 6, in which it is assumed that, if the signal is present it is at some exact position in space and time. The curve for M = 10 is based on the assumption that the signal may appear anywhere in a space expanded in area and time to include ten orthogonal positions of the signal. It is to be noted that, as the statistical uncertainty of the time and position of the signal

increases, the performance decreases, and, in fact, it decreases more for weak signals than for strong signals. This is a phenomenon frequently referred to as weak-signal suppression.

Presumably, if a receiver under study were unable to look exactly at a point in time and space, then it would produce an effect equivalent to introducing uncertainty at the transmitter. A plot of the performance of the receiver as a function of signal-to-noise ratio should permit one to identify the curve representing the same degree of uncertainty. This uncertainty would reflect two factors: (1) something like additive noise; and (2) faulty memory. The extent to which the memory is faulty is indicated by the slope of the curve, while the additive noise results in a horizontal transformation of the curve.

In Fig. 4, the data for one of the observers of Tanner and Swets(10) has been plotted over the curve for M = 100 of Fig. 3, a correction having been made for the horizontal shift. The result is interesting from a number of standpoints. First of all, one of the most difficult results of the Tanner and Swets paper to explain is the form of the relation between d′ and ΔI. The particular fit provides an explanation for the form of the relation. Consideration of the conditions under which the experiment was performed lend credence to the explanation. The temporal intervals were 2½ seconds in duration, marked by acoustic clicks at the beginning and end of the interval. The signal was 1/100 second in duration and came approximately in the center of the time interval. It would not be difficult to imagine that there is a considerable degree of uncertainty as to the exact time of the occurrence of the flash. With a relatively small uncertainty in position in the visual field, the product of time and location uncertainty could easily be as great as 100.

To summarize, first described was the concept of an ideal observer, one who performs to the limits of the environment. Next, the analysis of the limits of the environment was based on the statistical properties of photons. Then, the terms d′ and Q were defined. Finally, a theorem for employing these measures in an interpretative way was presented and illustrated.

REFERENCES

1. Lewis, W. B. Fluctuations in streams of thermal radiation. *Proc. Phys. Soc.* (*London*), 1947, **59**, 34-40.
2. Fry, T. C. *Probability and its engineering uses.* New York: Van Nostrand, 1929. 216-227.
3. Tanner, W. P., Jr., and Birdsall, T. G. Definitions of d′ and η as psychophysical measures. *J. Acoust. Soc. Amer.*, 1958, **30**, 922-928.
4. Jones, R. C. Quantum efficiency of detectors for visible and infrared radiation. *Adv. Electronics and Electron Processes 11*, 1959 (Academic Press, New York, 1959, ed. L. Marton). In press.
5. Rose, A. A unified approach to the performance of photographic film, television pickup tubes, and the human eye. *J. Soc. Mot. Pict. Engrs.*, 1946, **47**, 273-294.
6. Rose, A. Quantum effects in vision. *Adv. Med. Biol. Phys.*, 1957, **5**, 211-242.
7. Jones, R. C. On the quantum efficiency of scotopic and photopic vision. *J. Wash. Acad. Sci.*, 1957, **47**, 100-108.

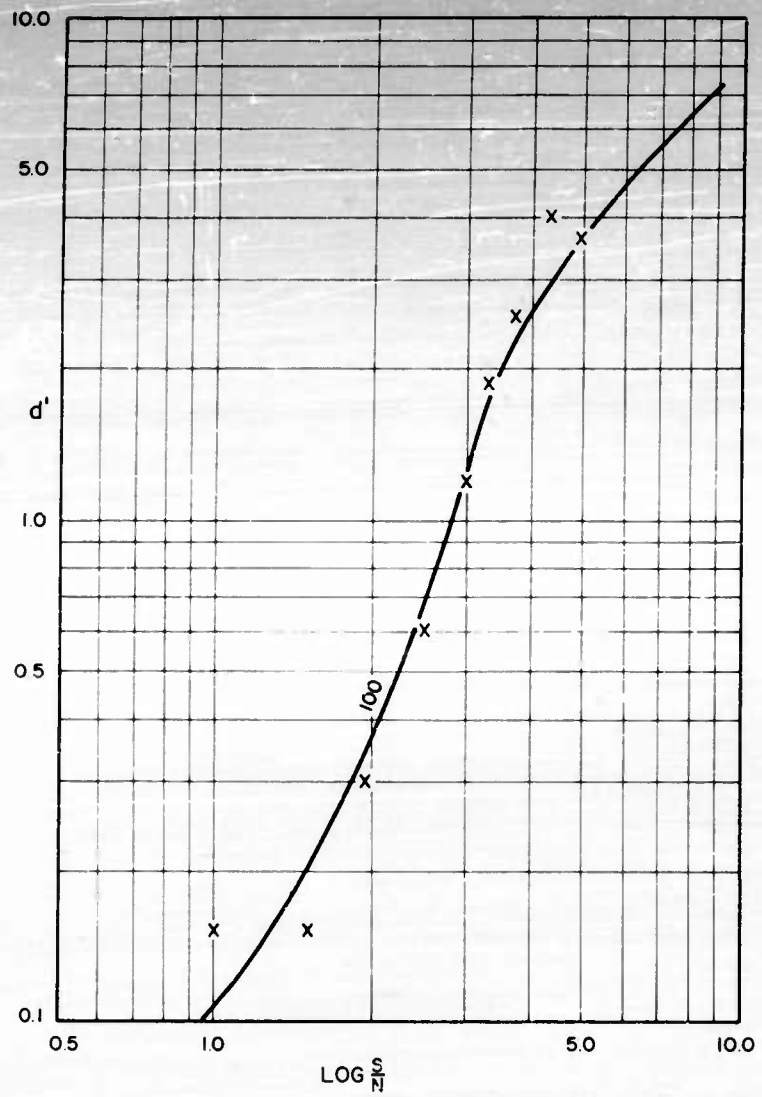


Fig. 4. A comparison of the data of Tanner and Swets with the curve for M = 100.

8. Fellgett, P. B. In F. B. Wood (Ed.), *Telescopes of moderate size.* Philadelphia, 1958.

9. Jones, R. C. Quantum efficiency of human vision. *J. Opt. Soc. Amer.*, in press.

10. Tanner, W. P., Jr., and Swets, J. A. The human use of information, Part I. *Trans. IRE Prof. Group on Information Theory, PGIT-4,* 1954, 213-221.

FACTORS TO BE CONSIDERED IN DEVELOPING OPTIMUM VISUAL SEARCH

JAMES L. HARRIS

The Visibility Laboratory carries on a broad program touching on virtually all aspects of detection and recognition of objects by means of electromagnetic energy within the visible spectrum. Specific areas pertinent to this conference include general radiative transfer theory, measurement programs in atmospheric and hydrological optics, visual psychophysics, and research in detection and recognition theory. The laboratory is frequently called upon to give numerical answers for specific visual tasks involved in military operations. We, therefore, have a group which we call Visibility Engineering. In recent years high correlation between theoretical predictions of visual search performance and subsequent field tests have given grounds for optimism as to our ability to make useful predictions. At the same time we realize that much remains to be done in this area.

The capability of performing successful visual search calculations involves essentially two factors. The first is the availability of all necessary visual psychophysical data. This is a large order for the psychophysicist in this field. The second factor is the development of proper tools of analysis for the task. This development of tools involves elements of operations analysis, statistical decision theory, and detection and search theory. Because much of the existing psychophysical data is of a nonanalytic nature, work is required in developing analytic approximations, where feasible, and graphical and computational aids, where the analytic approximations are not feasible.

Of course, any attempt to treat in detail all of these topics in this period would not only fail, because of time limit, but would also be presumptuous on my part. What I will attempt to do is to give a brief sketch from the point of view of one who attempts to obtain meaningful numerical results for the military's very real problems.

Starting with the concept of the visual detection lobe a target is placed along the axis of the fixational center of the eye and proper psychophysical experiments are performed. A relationship may be obtained between probability of detection and target contrast. If the target is now displaced from the axis of fixational center, a new function is obtained which, at high adaptation levels, will indicate that for equal detection probabilities, the off-axis target must have greater contrast. Translated to detection range this means that, for a given probability, a target will be detected at a greater range on axis than it will be off axis. Reference will be made to a plot describing the relationship between angular distance from the fixational center and detection range as a visual detection lobe. Figure 1 is an illustrative example of such a lobe. There are shown only two contours here; one for detection probability of 0.99 and one for a detection probability of 0.5. Many visual search calculations have been made assuming that the visual detection lobe is, so to speak, a "hard shell." That is, it is assumed that there is a contour such that if the target is outside the contour it is not detected, and if it is in-

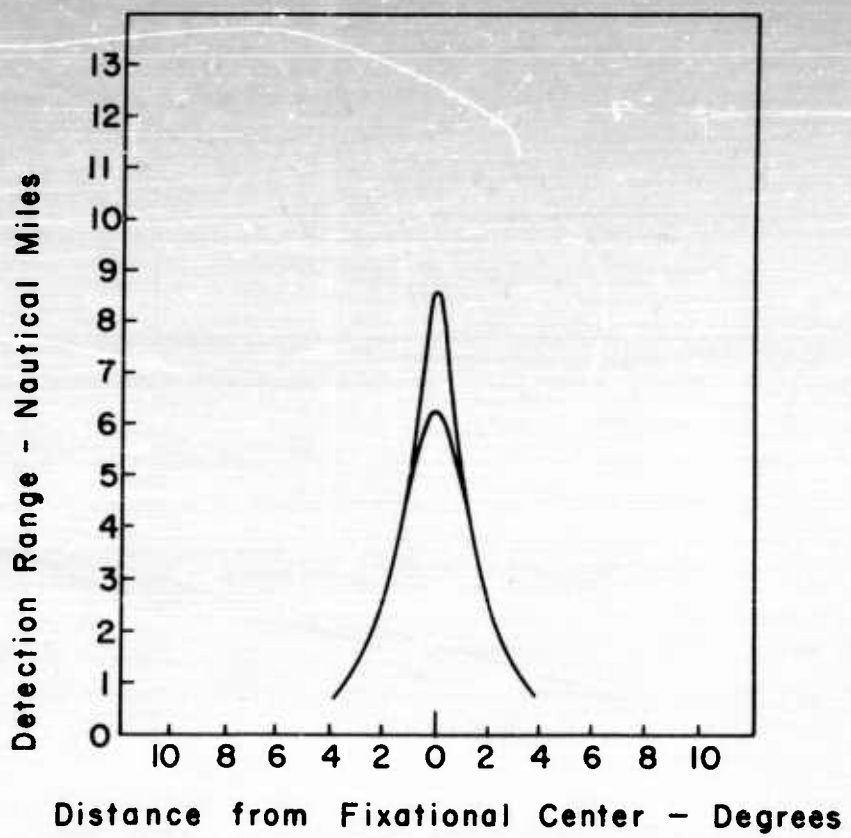


Fig. 1.

side the contour it is detected. This is an assumption which greatly simplifies analysis and on some occasions is a justifiable assumption. In general, however, it should be remembered that this lobe is not "hard shelled" but rather consists of a probability gradient.

Figure 2 shows a partial listing of the factors which determine the size and shape of the visual detection lobe. They are: adaptation level; target size, shape, and pattern; fixation period; target motion; field factors; and atmospheric transmission. Adaptation level has a profound effect on the shape of the visual detection lobe. Here this effect goes all the way from the high light level condition, where the cone vision of the fovea predominates (as in Fig. 1), to the low light level condition, where the rod vision predominates producing an on-axis dimple in the visual detection lobe. For high adaptation levels most visual search problems

PARAMETERS OF THE VISUAL DETECTION LOBE

1. Adaptation Level
2. Target Size, Shape and Pattern
3. Fixation Period
4. Target Motion
5. Field Factors
6. Atmospheric Transmission

Fig. 2.

require knowledge of the visual detection lobe over only the foveal region. For the adaptation levels near or below rod-cone crossover, data are badly needed over wide angular deviations from the fixational center.

A great deal of data exists for circular, uniform luminance targets. Some valuable work has been done on target patterns (form factors, etc.) and much less information is available on targets having a pattern or internal contrast variation. The effect of stimulus duration has been studied for certain targets. This information is assumed to translate directly to fixation period for the purposes of visual search calculation. The effect of target motion has not been sufficiently explored, although some methods of handling this factor have been suggested by research. There are many so-called field factors, which are required to translate laboratory data to field data. These include the physical and mental state of the observer, the conditions under which he must perform the search task, etc. It is often said that forced choice experiments are preferable in the laboratory because they yield more stable data. In the field it is the yes-no response which determines the visual search performance. It is obvious that at least part of this instability in yes-no data is due to the individual differences in establishing a criterion for detection. It is apparent that if there is variance in yes-no data collection, any constant which purports to correct data from forced choice to yes-no will exhibit this same type of variance. Exploration of the variance in this constant is, therefore, important in performing visual search calculation.

It is unfortunate that there are only a finite number of visual psychophysicists who work a finite number of hours each day. Unfortunate, because there are an infinite number of permutations of the first five parameters of the visual detection lobe. This clearly implies much interpretation and extrapolation of existing data to solve real problems. It is hoped that these psychophysicists do this wisely. From my point of view, one of the great opportunities of this meeting is to make sure that we are using the best available data and the wisest interpolations and extrapolations.

The last item is not psychophysics but atmospheric optics. Figure 3 illustrates one effect of atmospheric transmission on the shape of the visual detection lobe. The exponential nature of contrast reduction results in very little effect at ranges shorter than the mean free path length and increasing effect at the longer ranges. There is, however, far more to this matter of atmospheric transmission than this simple figure suggests. Data collected by the Visibility Laboratory's aircraft program definitely indicate that analytic models of the atmosphere, which have been used in the past, are poor substitutes for the data from real atmospheres. Fig. 4

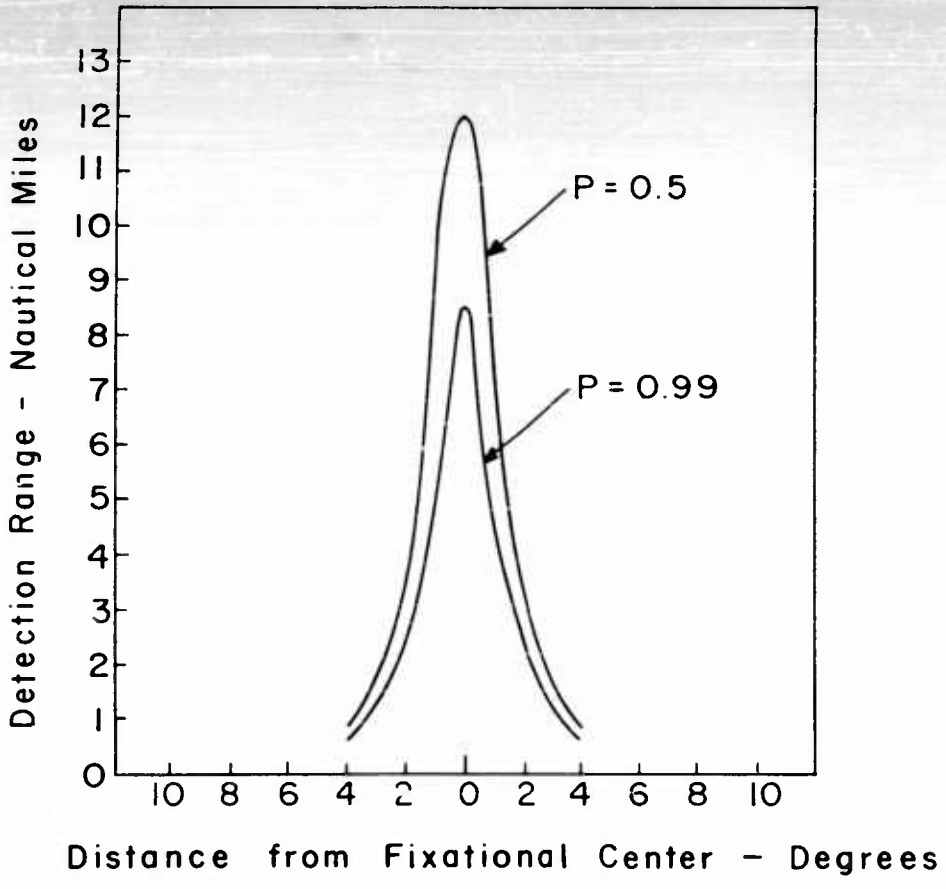


Fig. 3.

illustrates this fact. The irregular vertical curve is a plot of the horizontal range at which a specific target (size and contrast chosen arbitrarily) can be detected as a function of altitude. The curve was constructed using data from a typical day's flight. The short range at 2000 feet altitude indicates the presence of a haze layer. The smooth vertical curve, starting at about 6 nautical miles on the ground, is the detection range for the "optical standard atmosphere" based on the zero altitude data. Notice that at 2000 feet altitude there is a 4 to 1 error in detection range in the assumption of the "OSA." The smooth vertical curve initiating at 12 nautical miles at zero altitude is the upper limit to detection range. It is based on Rayleigh scattering. Notice that at 2000 feet, either neglecting the atmosphere or assuming Rayleigh scattering, the detection range is in error by a factor of 8 to 1. The writer would like to make a strong plea that workers be found *not*

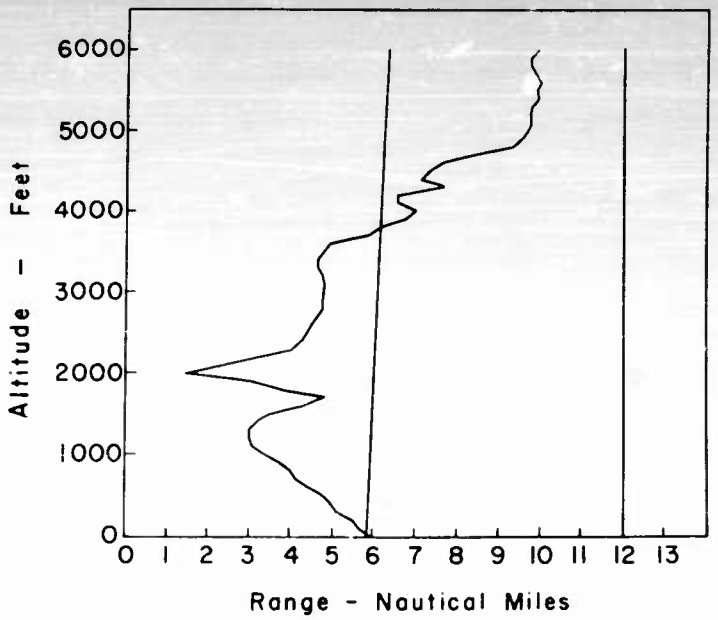


Fig. 4.

guilty of using high precision psychophysical data in conjunction with a sophisticated statistical analysis and then compounding this with an *assumption* about the characteristics of the target and either a poor assumption or *neglect* of the effect of atmospheric transmission.

Let us take some examples of search situations and examine the concepts involved. First, consider the case of a stationary target viewed against a uniform background. After defining the target and background (assumed to be a high adaptation level) the visual detection lobe is constructed. In the simplest case it may be assumed that we know the target range and know that the target, if it is present, is in a defined rectangular angular field of view. Before we begin our search, let us turn our back to the field of view and collect our thoughts. We know what the target is. We know the adaptation level. Therefore, we have knowledge of the shape of our visual detection lobe. There are two other questions we must ask. First, what is the relative frequency of occurrence of the target in each portion of the field of view? Second, how often do we expect a target to occur? With this information we can visualize an *a priori* map of the field of view; that is, at every point in the field of view we assign a probability that a target is present. The function of search is to improve upon this initial statistical estimate. It is convenient during the process of the search to consider separately another form of probability map. This is the map of conditional detection probability. For a conditional detection probability map we associate with each point in the field of

view the probability that *if* a target was present, it would have been detected. The overall detection probability is then a combination of the *a priori* map and the conditional map. Just to make an easy visualization, let us suppose that we decide a target is equally probable at every point in the field of view. Now consider the conditional map. Figure 5 is such a map prior to our first fixation. Here

Fig. 5.

we use the analogy, darkness is the absence of knowledge. The conditional probability of detection is zero at every point in the field of view. Figure 6 shows the conditional map after a single fixation. The light area is the interception of the visual detection lobe with the geometric plane of the target. The luminance is proportional to the probability associated with each point in the cross section of the visual detection lobe. The total conditional probability of detection is the average luminance of the entire field. That is to say, after a single fixation the

Fig. 6.

probability that a target *if* present would have been detected is found by averaging the luminance over the entire field. A complete search with unity detection probability can only be accomplished by making a succession of fixations in such a way that the whole conditional map becomes white. Figure 7 shows a second fixation in the field. The question is: Where should we place our second fixation? The answer is sometimes difficult to determine numerically but simple to state. We should make our next fixation at that point in the field where it will cause the greatest increase in the *final* detection probability. Unfortunately, this does not mean that the conditional probability associated with the next fixation should necessarily be maximized. To illustrate this we must now consider what we mean by optimum. Even after we have completely specified the target, its background and the *a priori* probabilities, we can only describe an optimum search pattern if

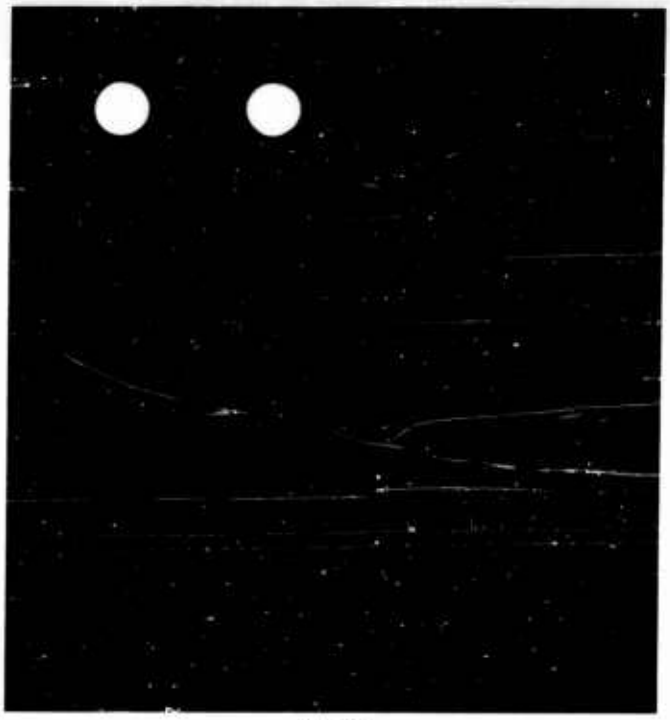


Fig. 7.

we define the time at which we wish the detection probability to be maximized. In other words, the search pattern which will maximize the detection probability at the end of one second of search is not in general the pattern which will maximize the detection probability at the end of ten seconds. To understand this we must take into consideration the several types of probability integration associated with the visual system. The first of these is illustrated by Fig. 7. That is, the overall probability of detection was doubled by the second fixation. If we had made the second fixation at a point where it would have overlapped the first fixation, the probability of detection at each overlapping point is found by digitalized integration. In other words, the probability at this point is the probability that the target would be detected by the first fixation or the second fixation or both fixations. This digitalized integration is less effective than the direct integration. For the two fixations shown, any overlap will result in a detection probability less than that due to two fixations which do not overlap. Therefore, if the time at which we

wish to maximize detection probability will allow us to make all of our fixations without overlap, we should do so. There is a detection probability limitation associated with nonoverlapping search. This is obvious to psychologists who have extensive experience with round pegs and square holes. You cannot completely cover a rectangular field with a circular pattern without overlap. Even if the detection lobe was a uniform circle (the "hard-shelled" concept), the upper limit to detection probability without overlap would be 0.7854, the area of a circle inscribed in a unit square. Because of the probability gradient associated with the lobe, the upper limit is considerably less. Roughly, we might say that when we have detection probabilities of 50% or higher, we are talking about search in which overlap of the visual detection lobe for successive fixations occurs.

If we take cognizance of all of these factors, we can determine a search pattern which will optimize the detection probability for a given search time. Figure 8 is a continuation of the search pattern initiated in Fig. 7. It is presented

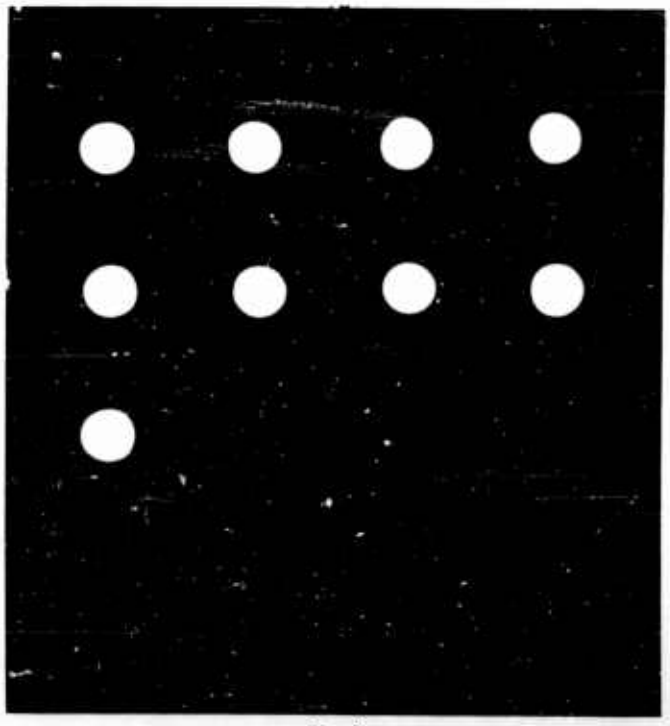


Fig. 8.

to emphasize that the conditional detection probability is the average luminance over the field.

In determining an optimum search pattern it is also possible to determine the optimum fixation period. It may be visualized that as the fixation period is reduced the diameter of the lobe intersections will increase. However, the reduced fixation period makes possible more fixations in a given search time. The fact that an optimum fixation period exists is indicated by considering the extremes of fixation period. For long fixation periods (i.e., one to two seconds) the visual detection lobe changes very slowly as we decrease fixation time. For example, in most search situations a change from two seconds to one second would be a desirable change, since the small reduction in visual detection lobe diameter would be more than compensated by the fact that we can now make twice as many fixations. On the other end of the scale there exists a fixation period so short that the target will not be detected. Some place in between, then, there must be an optimum choice. Visual psychophysical experiments must tell us the degree to which an observer can control fixation period and also the degree to which an observer can follow a prescribed search pattern. Obviously, our optimums are purely mathematical fantasy, if the visual system is incapable of operating in the manner prescribed by the analysis.

The purpose of the last several figures was to introduce the concept of a conditional probability field. For purposes of introduction we considered the simplest of all search situations, namely, the stationary target at known range. By leaving out all mathematical equations, I hoped to be able to develop the intuitive feeling as to the meaning of an optimum search pattern. The question, where should we put our next fixation in order that it will result in a maximum detection probability at the end of a specified search time? The use of the term "probability field" may sound like a "gilding of the lily," when thinking of the last several figures. In general, however, this probability map is not static as with the case of the stationary target. I would like to use the remainder of my time to show examples of dynamic probability maps or probability fields. I will not discuss them at any length. I will ask you to use your intuition and keep in mind the question, "where should I make my next fixation?"

The first case is one in which the target has radial motion towards the observer. Figure 9 shows a sequence of fixations under these conditions. Figure 9(a) shows the first fixation when the target is at considerable range. Figure 9(b) shows the first and second fixations. In the second fixation the target has moved toward the observer and is now detectable over a larger angular distance from fixational center. Figure 9(c) shows three fixations. A little reflection will make it clear that a search pattern, which will optimize the detection probability at the longer range, will be a poor choice for maximizing the detection probability at the close range.

Fig. 9(a).

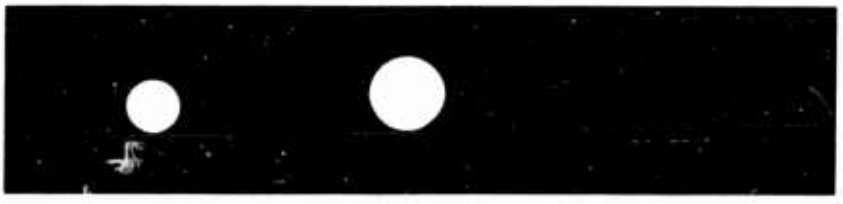


Fig. 9(b).

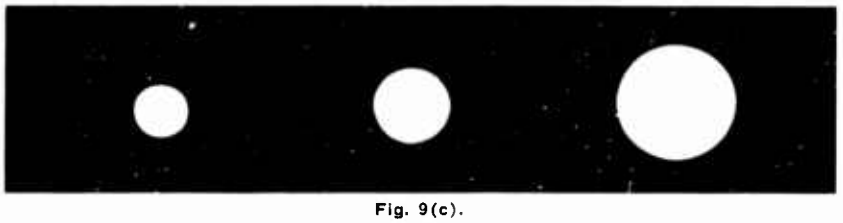


Fig. 9(c).

Figure 10 shows a situation in which we have lateral target motion of known velocity. Figures 10(a), (b) and (c) show the probability map at three time intervals associated with a single fixation. Let us assume Fig. 10(a) shows the position of the original fixation. We did not detect a target. We, therefore, have an amount of certainty described by the light area that there is no target there. If we make no other fixations and if the target velocity is known, then t seconds later this certainty as to absence of a target has shifted in our field to a new position, Fig. 10(b), displaced velocity times time from the initial position. Even though we have made no fixations in this new position, we have a degree of certainty that there is no target present there. Figure 10(c) is the probability field 2t seconds later. Note that at time t we could make another fixation at the initial fixation point with no redundancy of search. You can, in fact, invent special search geometries, where the optimum search pattern consists of making all your fixations at the same point in space.

Fig. 10(a).

Fig. 10(b).

Fig. 10(c).

Figure 11 shows an extension to the case of lateral target motion, where the speed is known but it is not known whether the target is moving left or right. Here probability field viewed t and 2t seconds after a single fixation, contains two areas of certainty as to absence of a target. The uncertainty as to direction reflects itself in a reduced probability at any point in the field, even though the total conditional probability remains a constant. If we wait a sufficient time, the probability areas will drift completely out of the field. This is stating that the single fixation no longer gives us any information as to presence of a target.

Fig. 11(a).

Fig. 11(b).

Fig. 11(c).

Figure 12 is an extension of Fig. 11, in which we are uncertain as to target velocity. The probability field undergoes a diffusion defined by our knowledge of target velocity.

Fig. 12(a).

Fig. 12(b).

Fig. 12(c).

Figure 13 shows a case in which target velocity (both speed and direction) are unknown. Again, the probability field associated with a single fixation undergoes a process of diffusion.

These are just examples. For every search geometry and assumption of target velocity we can describe a dynamic probability field. An optimum search pattern can only be defined if we use our knowledge of this dynamic field. It is only in this way that we can make our next fixation where it will do us the most good.

There is another profitable approach to visual search problems which should be pursued. This is the area of mathematical models of visual search. As a simple example, specifying the number of receptors in the eye, the quantum efficiency

Fig. 13(a).

Fig. 13(b).

Fig. 13(c)

of each, and the characteristics of the optics of the eye determines an upper limit to visual search performance. Application of detection theory in this way allows us to draw a set of performance curves with confidence that they will not be exceeded. For every additional visual system characteristic which we add to our simple model, we can draw a new set of performance curves defining an upper limit, which will be closer to real visual performance. These performance curves can be drawn for both detection and recognition functions.

In summary, from the point of view of one who is attempting to give real answers to real military problems, the research which must be pursued can be classified as follows. We must gain better information about the nature of the targets themselves. We must continue to define the effect of atmospheric transmission upon these optical signals. We must continue to gather psychophysical data to enlarge our knowledge of the effect of these optical signals on the visual system. We must generate new techniques and aids to computation of the statistics of visual search. And, finally, we must strive toward analytic models of the visual system, which will allow accurate prediction of the upper limit of performance for the visual system.

DISCUSSION

NANCY S. ANDERSON: I would first like to say that I was impressed by all of the papers in this session. Each paper has given information about search models and data which add to our knowledge about the process of visual search. Models describing search behavior are indeed often abstractions of the real situation, necessarily so in order to clarify the concepts involved and, in the end, to describe the situation in an organized and more or less quantitative fashion. It is true that when a theorist first abstracts a situation, some factors of the real situation may be omitted which are felt to be important. One often needs to make assumptions about secondary effects to discover a solution, even though approximate. With this in mind, it is difficult to criticize those factors omitted or over-simplified by the model. However, I do wish to comment on certain factors which have been discussed in these papers and offer some comments and questions about their usefulness and generality in describing visual search.

The concept of the visual detection lobe has been discussed by Mr. Harris. He cautions the use of the detection lobe as a "hard shelled lobe" and he clearly demonstrates the "softness" of this lobe as a function of the probability of detection. I would like to emphasize his point and discuss it a little further. Harris suggests there is a set of curves for any detection lobe as a function of probability of correct detection. Also, he suggests that we need visual lobe data for (1) adaptation level, (2) fixation period, (3) target motion, etc. This entails obtaining visual lobe data for a large but finite number of conditions. All of these data will still leave the question of interaction of conditions unanswered. For example, let us take detection lobe data as a function of (1) size of target, and, (2) shape of form of target. Let us suppose that one of the shapes in (2) was varied for all sizes to obtain lobe data as a function of size; and that one of the sizes in (1) was varied for all shapes to obtain lobe data as a function of shape. Are there data available about the interaction between size and shape? Is it possible to generalize the data from these two studies to a search situation in which both size and shape of targets vary, or is it necessary to permute all the various combinations before generalizations are possible?

For dynamic search situations, application of the lobe data for a single fixation assumes that the probability of detection lobe does not change from one fixation to the next. Harris describes different search strategies and the conditional probabilities associated with search fixations depending on target motion and position uncertainties. These two considerations lead to the following question. Do the search strategies influence not only the conditional probabilities of the location of fixations, but also the shape of the detection lobe at each of these fixations?

McGill's model is concerned with the time it takes to search for a particular stimulus target in a field of similar stimulus targets. That the search time scale is magnified as a function of the number of alternatives is indeed intriguing. I have a question about the use of the number of alternatives as the basic concept. In both McGill's and Volkmann's work, the number of alternatives or matrix size

appears to be perfectly correlated with the size of the visual field. What happens if one holds the size of visual field constant and then varies the number of alternatives? One possible outcome is that the only change is to alter the values of McGill's two parameters α and β. It may not be necessary to add a new parameter to the model if the ratio of the two parameters still holds.

I notice that both McGill and Volkmann use symmetrical matrices. That is, the number of columns equals the number of rows of information. I would like to suggest a caution here. In several studies concerned with pattern recognition of nonsense histogram figures, Weinstein found that recognition sorting times were a function of the number of alternatives. Results indicated that increases in the number of columns produced greater decrements in sorting time than did increases in the number of possible column heights (row additions).

With respect to the two time parameters being random variables in McGill's model, I find it is intriguing that this model fits the data even assuming random search strategies. This suggests that whatever strategy is used, the resultant performance is no different than that obtained by a random strategy. If there are data suggesting search is systematic, why does a random strategy model account for search behavior?

McGill's model suggests that the initial search is one in which the searcher randomly looks at all the objects hoping that one stands out or that he detects it by chance. There is evidence to show that the initial look or search is an orientation search in order for the searcher to discover what he is looking at or what is in the visual field. Perhaps it is this orientation looking which results in the initial search appearing to be no better than random.

The paper by Tanner and Jones describes a method for doing experiments in signal detectability. The search task described by these authors is one of detecting a signal occurring in time on a flat surface of uniform background. The purpose is to measure the detectability of the receiver compared to the "ideal observer." The "ideal observer" is a model whose strategy is described in terms of a statistical decision theory. One can perform experiments comparing the ideal observer detecting a signal in noise with the receiver under study detecting a signal specified exactly. By their theorem, if the same quantum efficiencies are found, then the receiver under study introduces the same degree of statistical uncertainty (through internal noise and faulty memory) as the ideal observer detecting the signal in noise. Essentially, the receiver is the ideal observer working with a different signal-to-noise ratio. If the model is to be useful it must be possible to calculate this uncertainty for various tasks. Moreover, this uncertainty must have some constancy for an individual and vary systematically for changes in the visual environment so that useful prediction can be made to search situations. The calculation of the uncertainty to be added at the transmitter for different tasks should help us gain insight into the strategies used by the receiver under study.

Harris mentioned the difficulties in applying data from the forced-choice laboratory tasks to "yes"-"no" field studies. With the knowledge we have about

types of errors in "yes"-"no" experiments, perhaps the forced-choice approach should be attempted in field experiments.

In conclusion, I want to again compliment the authors for isolating concepts that are important parameters in visual search. Furthermore, using these parameters in a model which can be evaluated quantitatively gives a firm framework for testing hypotheses. It would be helpful to see some of the suggested search strategies tested against the "ideal observer." In closing, Volkmann's data are useful for describing visual search techniques, and his data on search rates should give insight into some of the problems that arise in the training of searchers.

WARD EDWARDS: Let me start by saying that I am deeply impressed by all four papers in this session. I feel that they represent important contributions to thought about visual search problems.

My second comment is that two of the papers, McGill's and Tanner's snowed me completely. I am reluctant to exhibit my mathematical ignorance before so distinguished a group, but those papers were simply over my head.

It occurred to me that some of you might have been snowed also. I feel sure that most of you had no difficulty following McGill and Tanner, but a few of you may be as deficient in mathematics as I am. So I suggest that all who understand them take a nap, or a drink, or twiddle your thumbs while I try to tell the the few who know no more mathematics than I do, in non-mathematical language, what I think McGill and Tanner said.

McGill is concerned with the process of finding one designated object in a field of similar objects, and his model concerns the time it takes to do this. His fundamental point concerns what he calls time magnification. By this, if I understand him rightly, he means a quite specific technique for examining small perceptual differences. If two slightly different perceptual objects are to be compared, they should each be embedded in the same set of background alternatives. The slight difference between the two objects will lead to small differences in the amount of search time required to hunt them out from their backgrounds. Furthermore, this difference in search time will increase as the number of background objects increases; this effect is what McGill is calling time magnification. Volkmann's data show it also. The rest of McGill's paper, including almost all of the mathematical part of it, is concerned with a mathematical model for search behavior, the fundamental assumption of which is that search time has two components. The first of these is a reaction time, and the second is the actual time spent searching. Both of these times are assumed to be random variables having particular distribution functions, and the mathematical developments concern the distribution of the sum of these two variables.

Tanner's paper is somewhat more difficult to summarize in non-mathematical form. Tanner's fundamental idea is that the task of the observer in psychophysics is to choose between two alternative risky courses of action, one of which is asserting that a signal *is* present in a particular stimulus, the other of which is asserting that it is not. Tanner then asks how such risky decisions should be made.

The answer, of course, is that the course of action with the higher expected value should be chosen. Tanner's mathematics consist essentially of an analysis of how often a subject who consistently chooses the answer with the higher expected value would be right and how often he would be wrong.

This approach immediately gives rise to two questions. The first is: what is the reward for being correct or the punishment for being wrong in a psychophysical experiment? Tanner's paper does not discuss this problem, because it doesn't matter; all he needs to assume is that it remains the same after the subject makes his observation as it was before he made it. His real concern is with the effect of the observation on the *a priori* probability that the signal is or is not present. Here his mathematics simply applies in a very sophisticated way an old and problematic theorem from probability theory known as Bayes' Theorem.

The second question raised by Tanner's approach goes as follows: of course subjects don't always make the prediction with the higher expected value (a fact which Tanner makes explicit by talking about the ideal observer and by calling his point of view signal detectability theory rather than signal detection theory). How does this kind of model deal with real subjects? Tanner's answer consists essentially of a procedure which enables him to assert that a subject performs as well as an ideal observer would have, if the ideal observer had been confronted with a lower signal-to-noise ratio than the real subject encounters. In other words, Tanner deals with real subjects by treating them as though they were ideal observers working under more difficult conditions than are really there. A very inexact intuitive way of understanding this notion is to think of the subject as being a computer which always chooses the bet with the higher expected value, but is handicapped by having eyes and ears which add substantial quantities of noise to any inputs they receive.

Now that I have attempted to summarize McGill's and Tanner's papers in non-mathematical language, my remaining responsibility as a discussant is to be constructively critical. In the cases of the Harris and Volkmann papers, that is somewhat difficult; I find little in them to criticize. It is much easier to criticize the McGill and Tanner papers. The discussant is always in a good spot when he discusses a paper concerned with a mathematical model. He can always safely start by saying he doesn't understand the mathematics and then equally safely go on to stigmatize the assumptions as oversimplified. This time-worn strategy has worked before; I have used it just now.

First, I want to discuss the nature of the target in visual search. As I see it, the typical visual problem of military interest is the problem of finding a tank in a forest. This target is complex and nonhomogeneous. So is the background in which it is embedded. And the probability of finding the target in a given location is not homogeneously distributed over all locations in the visual field, or even over some large set of them.

Two strategies for dealing with this real-life problem are possible. One is to attempt to transfer it into the laboratory wih its complexities intact in so far as possible. This strategy presents formidable difficulties of both a theoretical and a

practical nature. The second strategy, of course, is to simplify the problem sufficiently to make it amenable to reasonable theorizing and experimentation. The danger of such simplification, of course, is the danger of throwing out the baby with the bath — of simplifying the problem until it isn't the problem of visual search any more. I think both McGill and Tanner have managed to do this, in quite different ways.

The most significant sentence in McGill's paper, it seems to me, goes as follows: "All this randomizing (of target identity and location) turns out to be necessary in order to wash out local effects due to peculiar configurations of alternatives." These local effects due to peculiar configurations of alternatives, I assert, are exactly what visual search is all about. Once you randomize the nature of the target, the location of the target, and the relations among sequences of targets, what non-random information is left? Very little. It is not surprising that under these circumstances a model which in effect asserts that the search strategies which subjects may use are irrelevant, and so subjects may be treated as though they simply look wherever their eyes happen to be pointing at the time and then randomly change what their eyes are pointing at — it is not surprising that such a model gives a good fit to the data. But I feel sure that subjects actually perform visual search tasks systematically. For example, Harris has pointed out how information about possible target motion should influence visual search strategies. His argument is clearly correct as an argument about what subjects should do; one of the fundamental empirical problems of visual search is whether subjects do in fact adapt their search strategies to the nature of the information they have. But this problem, and indeed any other problem you can think of concerning the strategies which subjects actually use in making visual searches, is carefully washed out of McGill's experiment and theory. It could, of course, be argued that McGill's model provides a baseline from which performance in situations in which more systematic search strategies might pay off will deviate. Maybe so. But in that case why is it necessary to make *ad hoc* assumptions about distribution functions? If we accept as baseline so radically simplified a situation, shouldn't we be rewarded with some model which gives a deeper picture of the search process than simply saying that there are reaction times and search times?

Tanner makes a bold attempt to make his equally vigorous program of simplification pay off in just such a deep picture of the search process. His picture is concerned with correct responses and errors, rather than detection times — already a step in the right direction, in my opinion. And his model is both intuitively appealing and mathematically deep. The only trouble is, it isn't a model of human visual search. McGill threw away searching; Tanner throws away both searching and the searcher. No more than McGill does, he attempts to take into account the interaction between strategies and the real-world inhomogeneities which make such strategies useful or harmful. But in addition he makes almost no attempt to predict what people will do; instead, he talks about what people could do if they were ideal observers. Of course he does allow people to be less than ideal. As I pointed out above, his method of doing this is to treat a real observer as equivalent to an ideal observer faced with a lower signal-to-noise ratio

than is actually present. In effect, this uses noise as an intervening variable in a model of human behavior. If this intervening variable varied lawfully either with the individual or with the situation in which he is put, that would be dandy; noise as an intervening variable is neither more nor less peculiar than habit strength. But I have been unable to find out what laws this intervening variable is supposed to obey in its relation to situational factors, with the sole exception of some *ex post facto* uses of statistical properties of inputs as hypothetical generators of noise — or rather, as generators of hypothetical noise. Incidentally, I should call your attention to the fact that in order for the statistics of Tanner's model to work, the noise must be statistically simple — in fact, it must usually have a Gaussian distribution. Conceptually, the model can get along with any kind of noise, but the calculations increase in difficulty whenever something other than band-limited, white Gaussian noise is used, and only for that and some other rather restricted kinds of noise are the calculations possible at all.

Before leaving McGill's and Tanner's papers, I would like to return to the tank in the forest — the real-life visual search problem. Both McGill and Tanner have tried to simplify the problem by simplifying the environment until it is easily describable in convenient statistical ways. But another approach is possible. The most urgently needed development in the field of visual search, in my opinion, is the development of a satisfactory general mathematical technique for describing visual environments. Attneave and Arnoult have made some attempts in this direction, as has Green, but a great deal more remains to be done. Cannot we somehow persuade fine mathematicians who have deep experimental sophistication also, like McGill and Tanner, to attack this problem rather than simplifying it out of existence?

I would like to justify my somewhat unfair criticisms of two really excellent papers by quoting Ailene Morris's instructions to discussants. "To me, the discussants are 'plants' in the audience to stimulate discussion and fan the flames of controversy." I have at least tried to put a few matches into the kindling.

H. RICHARD BLACKWELL: I find myself in surprising agreement with the two discussants who had the opportunity of reading the papers in advance of hearing the discussion. I want to go a step further than either one of them. In past years before the Vision Committee, at least after 1945 if not before, there has been a tremendous amount of emphasis on what was called today "visibility engineering." As one of the early practitioners of the art I want to make rather derogatory remarks about where I think it is heading. I think this is a confirmation of the two discussants' remarks. In original concept going back to the wartime work of Hardy and Duntley among others, I took the position that it should be possible to collect laboratory data on the eye and field data involving atmospheric optics and to put these together to predict the visibility of targets in real life situations. Considerable effort has been devoted to studying the eye and studying the atmosphere as stated today, particularly on the part of the Visibility Laboratory in California. Considerable effort has been devoted to putting the pieces together to predict performance. Now in the broad sense it seems to me we just heard four papers that you might say had to do with operations analysis of the problem of visual

detection during search, and these differ in detail. This is, I think, one extreme form of the argument. Now basically what I am trying to do here is question seriously whether the time hasn't come for a partial abandonment at least of this long standing, well developed technique of visibility engineering. For example, suppose we start with the elements of this theory. In a sense none of the papers put this all together, as was pointed out by the discussants, but let us suppose they had said that the signal detectability theory had been fully developed into a visual search theory, and I think that my criticisms would still apply. As far as the detection theory is concerned, it should be clear that the Tanner theory, as here proposed, and the theory that I myself have proposed in the past makes the simplifying assumption that there is no qualitative difference between signal and noise. I think that this assumption isn't too bad; experiments bear this out under the simple conditions of a perfectly uniform background and a perfectly uniform target. As Ward Edwards so nicely pointed out, this has nothing to do with most practical problems of air-to-ground. It may not be too bad when one talks about air-to-air or even air-to-water cases, although I think air-to-water is questionable. Air-to-air is the most likely one to be successfully described in this way. Now, of course, Tanner went us one better and replaced the nervous system with the quantum theory, which is by no means a new idea. It had great vogue in Europe for at least fifteen years. One can question whether, indeed, the human organism works on the basis of quantal distributions. This, I think, has been somewhat successful, but certainly it is not the whole story.

Now secondly, suppose we had criticized the detection theory as such. We next question the detector lobe concept, as has been done by Dr. Anderson. This lobe is based upon visual detection data under the simplified conditions of the uniform field and the uniform target. I am not for the moment trying to jump to the complex situations, but merely pointing out that the detection lobe is known to be different for the different visual tasks; yet throughout the analysis the detection lobe for the uniform target has been used. Now finally and perhaps most important it seems to me, and this Dr. Anderson also mentioned, there has been the assumption, that in model building based upon detection theory, in turn based on detection lobes, an empirical fact, one has independent probabilities of the events which occur at successive moments in time during the directing of one's detection lobes from point to point throughout visual space. I am not, at the moment, arguing as Dr. Anderson did, that people do not in fact follow the photocell scanning technique. They are not like radars — they are not that stupid; they just don't look uniformly from point to point as the detection theories have suggested. They do reasonable searching and scanning based upon information selected from the environment. But I am not emphasizing that point, I am saying that at the heart of all these theories there is the assumption that there is independent statistical addition of events which occur at successive movements in time. I maintain this is the most unlikely assumption that one can possibly make and it is completely counter to most everything we know about the visual system. The difficulty is that we don't know enough. One cannot disagree that we have need for further research.

NANCY S. ANDERSON: I would like to defend and clarify what was said in the discussion. The point I was trying to make is that the independence from one look to the next may not be true. It was Dr. Edwards who suggested the study of parameters of the structure of the visual field.

SEIBERT Q. DUNTLEY: I have had the advantage of having read the manuscripts of some of tomorrow's papers. I want to point out that some of the items which Dr. Blackwell was mentioning a moment ago and some of the items, mentioned by Dr. Anderson, are going to come up tomorrow. I believe that a discussion of them today is a little bit premature. I think that after tomorrow's papers they can be discussed on a broader base, and I suggest that we not go too far on this train of thought until nearer the end of the meeting. I would like to point out, however, with respect to all of the papers that the scientific method has been usefully applied to a good many fields of endeavor and the best interests of mankind have not been served by turning away from it. The science of visual search may be incomplete but I am confident that eventually we will be able to do everything necessary for practical purposes by scientific methods.

The Vision Committee has been meeting for a long time and some of us remember the early days when we used to have many down-to-earth discussions of research needs; many important programs of investigation started that way and I hope that our meetings never get away from worthwhile discussions of this type. I would like to make a plea for more visual lobe data. There is a very real need for these data. The lobe concept has been used by some of us for many practical purposes for nearly 15 years. Visual search calculations form the basis of many intricate and wonderful studies, some of which have been validated by field test. They are of established military value. But all of these studies are based on a very small amount of visual detection lobe data. I think that this is not fully realized. Dr. Lamar mentioned it but I would like to emphasize that Craik in England collected the lobe data which he used during the war and nearly everybody has continued to use Craik's data throughout the ensuing years. These were hastily collected under adverse wartime conditions as Craik carefully pointed out. A more elaborate experiment was done by Dr. Muldower in Dr. Blackwell's group but it was limited to point sources and to millisecond flashes. The extent of the applicability of the Muldower data to practical visual search problems remains to be established. The lobe shape depends on the nature of the target and on a whole list of other factors that Mr. Harris mentioned. Although there have been several other smaller studies that have produced certain lobe data, it almost always turns out that no truly applicable lobe data are available when a practical visual search calculation is to be made. This is serious handicap, and I strongly urge research workers in vision to include peripheral threshold studies leading to detection lobe data in their programs. It is not enough, under a great many circumstances, to think of a detection lobe of fixed shape centered on the visual axis and directed by the eyes' movements. Often the shape of the lobe changes depending upon the direction in which the observer looks. This change in lobe shape is caused by the atmosphere, because the contrast transmittance along downward paths of sight depends upon the steepness of the path. The lobe is after all, a plot of detection range.

Search calculations are more complicated when the lobe shape changes as the eye performs its search, but this complication is not an insurmountable barrier, particularly when the work is programmed on a large computer. The art of visual search calculation is advancing very rapidly and the time is not far away when real input data of high quality will be available for virtually every part of every calculation, including the eye properties, the environment, the object searched for, and so on. To summarize: I want to plead for better and more realistic lobe data, real data on environmental properties, and the use of advanced computational techniques.

W. P. TANNER, JR.: I would like to set the record straight on a couple of things. I had no intention of saying anything about neural activities or neural quanta. The quanta that I was talking about were strictly physical. In the second place, the model which I present is a tool, an experimental tool which I hope will permit predictions from laboratory data which may have bearing on the search problem. I am not presenting a model of visual search as such; it is a tool, and I think that the model should be judged on its usefulness as a tool.

J. M. ENOCH: There are a few points that I would like to comment upon. First, many of the experimenters presenting papers today are assuming randomness in search. Frankly, our experience has been that search, at least on complex displays, is not random either in terms of distribution of eye fixations, or in terms of eye movement and eye fixation patterns. Our data reveal considerable redundancy in fixations, marked attention to highly visible objects, and a marked tendency for the individual eye movements and eye fixations to be influenced by the physical characteristics of the display. In essence, one is asking, what is the role in the peripheral retina in search? If it is not passive, it is doubtful that randomness can be predicted. Since, many of these points will come out in tomorrow's discussion, as very properly pointed out by Dr. Duntley, I shall defer further discussion on this matter.

The second point I would like to make is that we are in what might be termed a descriptive state in terms of our knowledge concerning search. As such, it becomes necessary to first define the basic variables, i.e., the main problem or problems. Hence, while theoretical models are most important, I wonder if it is not a mistake, at this time, to push theoretical models (particularly models covering only a small segment of the problem) too far and too fast.

Lastly, I would like to comment upon the question of decision-making and decision-making theory. I do not wish to enter into the argument raised by the previous speakers. Rather, I would like to suggest that there are certain decisions inherent in search which I think could be very profitably examined and studied. First, if an individual is fixating a given point on a display, what are the parameters involved in the decision to fixate the next point on the display. In other words, how does the individual choose among the N competing stimuli within the field of view when fixating a given point. The value of N may vary from zero to infinity, and the characteristics of these N points may vary in size, angular distance from the point of fixation, form, and contrast. Another important decision

which is very closely associated with what we call payoff is the decision to end search. This decision, as has been pointed out by Dr. Fry, is affected by many factors including prior knowledge of the existence of the object sought. Our data reveal marked individual differences in approach to this problem. Hence, a careful study is needed into the parameters involved in the statement that a given object (or N individual objects of a class of objects) is (are) or is (are) not present on a display. I feel that this information would be most important in terms of our really getting practical results from our search studies.

AILENE MORRIS: I must add a word of appreciation for the excellent job done by the military representatives in the first session this morning. They did *exactly* what was needed for this symposium. While informing us of the present operational practices, they answered some questions for us concerning best search procedures which have been developed through experience in the field. They also raised many challenging questions and have provided us with the *real* justification for holding this meeting. Apparently eyes are here to stay and at present there are no quick and easy "do-it-yourself" rules for their best use in visual search. However, we should have some of these rules by the end of the symposium tomorrow.

EDWARD S. LAMAR: I would like to say just a few words in this discussion. First of all, I was delighted to hear so much criticism of the papers of this session including my own. It means to me that at last people are taking a vital interest in the real problems of visual search. The question at issue, it seems to me, is how best to handle practical operational problems. Here there are two choices; either one obtains an exact solution to an approximate problem or an approximate solution to the real problem. The work on which my paper was based employed the latter approach. With so many people now interested and taking part, the prospects seem good for better solutions to follow.

SOME EFFECTS OF TARGET MICROSTRUCTURE ON VISUAL DETECTION

STANLEY W. SMITH and RICHARD T. LOUTTIT

The shape or configuration of an object is one of its most important characteristics for all types of visual observation. Shape is a significant variable even at detection levels. In a series of studies carried out at the University of Michigan under the direction of H. R. Blackwell, the effects of target shape on detection were determined for large ranges of other conditions such as background luminance, target size, exposure duration, color and retinal location. In general the results indicated that circles and other compact figures are easier to detect than figures which are of equal area but are more extended. However, extended rectangles are easier to detect than spatial summation theory predicts. Thus it seems that shape factors other than compactness contribute to detectability.

It occurred to us that spatial correlation might be involved in detection in such a way that if the elements of a visual target were highly ordered the target would be easier to detect than if the elements were distributed at random.

To investigate this possibility the targets shown in Figs. 1, 2, and 3 were con-

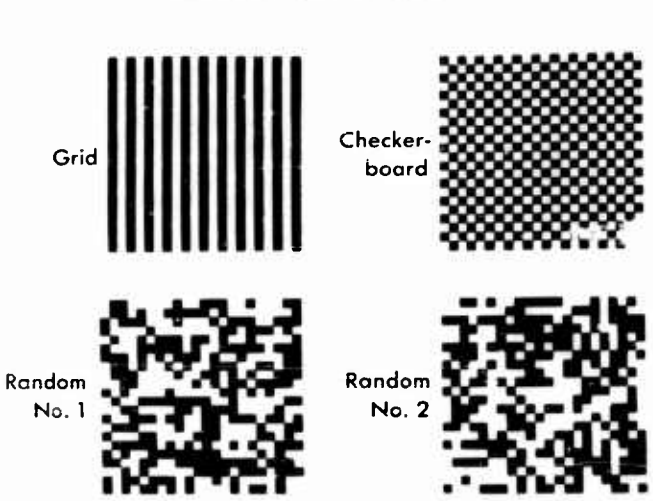


Fig. 1.

structed. The first figure shows a set of four targets each of which contains the same number and size elements. The upper left target is called a grid and the upper right one a checkerboard. Both of these targets contain highly ordered arrangements of elements. The other two targets consisted of elements distributed at random. All targets were of equal area and luminous flux.

Since the visual system does not function in the same way at different adaptation levels, and for short *vs.* long stimulus flashes, we compared detectability of the various target patterns at very different values of each of these parameters. Zero and 29 foot-lamberts background levels were used with both 0.01 second and 1.00 second exposure durations. Element size ranged from 1.33 to 3.44 minutes of arc for different experiments. In some cases the orientation of the figures was vertical as shown in the slide, and in others the figures were rotated 45 degrees. Figure 2 shows the targets which contained 196 elements; and Fig. 3, the targets containing 784 elements.

196 Element Targets

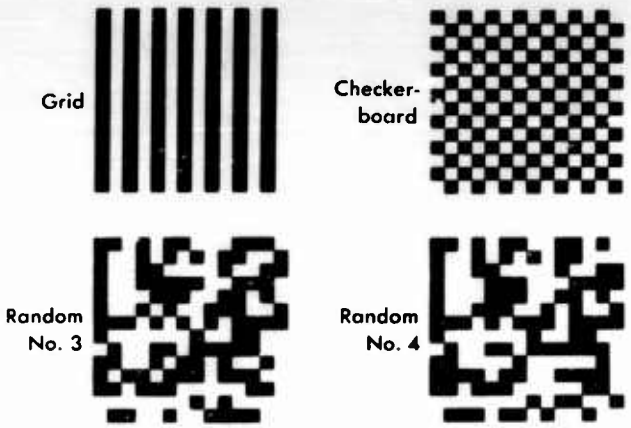


Fig. 2.

The procedure involved the presentation of a target at one of five luminance levels, in one of four time intervals. Spatial search was minimized by providing small orientation lights which outlined the area in which the target would appear. In this way target presentations were restricted to the fovea. Binocular vision with natural pupils was used throughout the experiments. Temporal search involved looking for the target during four well defined time intervals. The observer's task was to select and indicate the one interval in which the target was flashed. The critical interval and target luminance were varied randomly. This method is known as the temporal-forced-choice psychophysical procedure. In each session data were collected for three or four observers simultaneously. Thirty stimuli were presented at each of the five difficulty or luminance levels for each of the four patterns. The observer's responses were recorded and used in a probit analysis to determine detection thresholds. The data were also analyzed for significance of differences of total number of correct responses between the different targets. A criterion level of one per cent was used for significance.

784 Element Targets

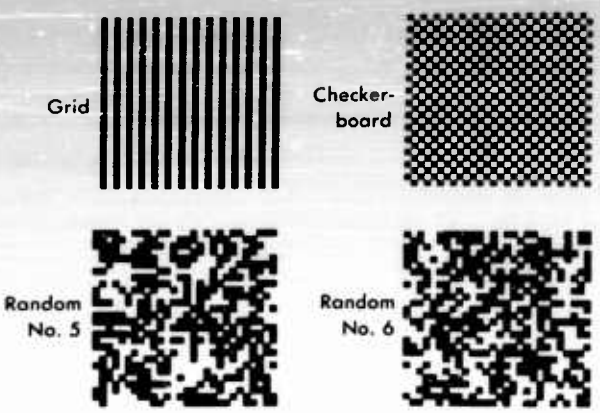


Fig. 3.

Now for the results. Table 1 summarizes the results in a tabular form which indicates conditions for which the data were different for the various target configurations. The direction of the difference in terms of threshold is indicated by "less-than" signs. G stands for grid, C for checkerboard, and R for random. NS stands for not significant. The data represented by NS in parentheses were collected in an earlier experiment. Since the orientation of the figures did not seem to have much effect on the data, and because the availability of our observers was limited, we did not use both of the orientations for all conditions.

TABLE 1

Target Exposure Duration	Background Luminance (Foot-Lamberts)	Small		Medium		Large	
		V	O	V	O	V	O
0.01 Second	Zero	(NS)	—	NS	NS	NS	—
	29	(NS)	—	NS	NS	NS	—
1.00 Second	Zero	NS	—	NS	NS	NS	—
	29	NS	—	G<C	G<C	G<R<C	G<R<C

Two important conclusions can be drawn from this summary of the data. First, the various target patterns differed in detectability only when they were exposed for a relatively long time at high background luminance. And second, under these conditions the grid pattern was the easiest to detect and the checkerboard pattern was the most difficult. The random targets were of intermediate difficulty. Thus, the degree of organization of elements *per se* is not a fundamental variable for detection.

In general, the results for the individual observers were in agreement with the summarized results.

Since there is not enough time to present all of the individual data, samples will have to suffice. Table 2 shows the data from one session in which highly

TABLE 2

196 Element Targets

1.00 second flash,
29 foot-lamberts background, vertical orientation

Observer	Target	Δ B	Significance
SWS	Grid	<0.179	<R#3, R#4, C
	Random #3	0.293	>G
	Random #4	0.268	>G
	Checkerboard	0.374	>G
JT	Grid	<0.179	<R#3, R#4, C
	Random #3	0.329	>G
	Random #4	0.312	>G<C
	Checkerboard	0.417	>G, R#4
RTL	Grid	<0.179	<R#3, R#4, C
	Random #3	0.347	>G<C
	Random #4	0.293	>G<C
	Checkerboard	0.538	>G, R#3, R#4

significant differences were obtained. This example was selected to indicate magnitude of threshold differences and consistency among observers. The threshold values for the checkerboard pattern in terms of foot-lamberts were more than double those for the grid. The differences were so large that the thresholds for all four targets could not be accurately determined with the same set of target luminance values.

Table 3 shows additional results obtained with the same observers and con-

TABLE 3

196 Element Targets

0.01 second flash,
29 foot-lamberts background, vertical orientation

Observer	Target	Δ B	Significance
SWS	Grid	2.055	NS
	Random #3	2.131	NS
	Random #4	2.007	NS
	Checkerboard	2.158	NS
JT	Grid	1.575	NS
	Random #3	2.031	NS
	Random #4	1.719	NS
	Checkerboard	1.937	NS
RTL	Grid	3.036	NS
	Random #3	3.294	NS
	Random #4	3.218	NS
	Checkerboard	3.385	NS

ditions except that 0.01 second exposure duration was used instead of 1.00 second. In this case none of the differences was significant.

Since this was an exploratory study, the design was not meant to reveal the underlying fundamental visual mechanisms involved. However, the fact that differences occurred only with high background luminance in combination with long exposure duration and larger elements points to the possible relevance of eye movements, rapid retinal adaptation and reduction of lateral neural spread of excitation. Whatever the important factors may be, it does seem that long straight borders between light and dark areas are facilitative, and that studies investigating this characteristic of visual targets are of great interest for detection as well as for search and for other visual functions.

DETECTION VERSUS LOCALIZATION ERRORS ON VARIOUS RADII OF THE VISUAL FIELD

E. RAE HARCUM

The problem of this paper is to distinguish between two factors affecting accuracy of reporting the location of a target, which may appear tachistoscopically on a radius of the visual field eccentric to fixation. Whenever the observer is asked to report the radial location of such a target, two of the factors affecting performance are, first, the capability of the observer for detecting the presence of the target, and, second, the ability of the observer to localize correctly the target once he has seen it. Let us call the former, "detection sensitivity," and the latter, "localization accuracy." The present thesis is that detection sensitivity is greatest for targets to the right and left of fixation, and poorest for those targets above and below fixation, but that localization accuracy is best for targets above, below, right and left of fixation, and poorest for those targets diagonally displaced from fixation.

Differences in performance among the various radial areas of the human retina eccentric from fixation, representing corresponding areas of the visual field, are ubiquitous. Examples of visual tasks in which such differences have been obtained are those nominally measuring detection sensitivity, visual acuity, form recognition, visual attensity, reaction time to visual stimulation, pattern recognition, estimation of numerosity, localization of radial position, and recognition of words or symbols. The above list is not exhaustive, and the various categories of visual task are, of course, not mutually exclusive. Not all of them will be considered here. In particular, the possible factors influencing differences between the right and left halves of the visual fields such as eye dominance, cerebral hemisphere dominance, and so forth, will not be discussed, and the emphasis will be on binocular viewing. Similarly, possible differences between top and bottom halves of the visual field will be ignored in order to simplify the problem.

Detection Sensitivity

Concerning detection sensitivity for the various eccentric portions of the visual field the consensus of experimental results seems to be that the areas above and below fixation exhibit higher thresholds and those areas to the right and left of fixation yield lower thresholds. The iso-detection contours for stationary spots, then, are generally oval with the long axis corresponding to the horizontal meridian of the visual field. This result has been obtained, for example, with scotopic illumination by Sloan(1) and by Blackwell and Moldauer[1] at both photopic and scotopic levels of illumination.

Form Recognition

The data from form recognition by the peripheral retina support the conclusion, particularly with respect to binocular viewing, that the horizontal axis of the

[1]Personal Communication.

form field is most extensive and the vertical axis is shortest(2, 3, 4). This result corresponds to the detection sensitivity data.

Visual Numerosity

The estimation of number for discrete target elements presented at various radial positions in the visual field is least accurate for targets arranged on the vertical meridian of the visual field(5, 6). Probably, again, the horizontal meridian is best on this type of task(6).

Pattern Recognition

Accurate recognition of a pattern of elements arranged along a meridian of the visual field and passing through fixation occurs most frequently for horizontal targets both when there is background noise, as there was in an experiment by Shetler, Berbert and Finney(7), and when there is a uniform background, as in studies by Harcum and Rabe(4, 6). Shetler, et al., used as a performance measure the accuracy of localization of the target meridian while Harcum and Rabe scored the accuracy of reproducing the pattern itself. Shetler, et al., did not report whether differences between the vertical meridian and the diagonal meridians were found. Assuming that their task involved a large radial localization factor, the present argument would predict superior performance for the vertical orientations when compared to the diagonal orientation.[2] The Harcum and Rabe task, which presumably measured one aspect of retinal sensitivity, produced generally poorest performance for the vertical radii. Of course, the one experiment employed a uniform background and the other a noisy background for the target patterns.

Visual Acuity

The term of visual acuity is perhaps too broad for present purposes, since it includes a great many tasks formally dissimilar to one another. In the case of acuity objects composed of circular patches of a line grating, the conclusions about meridional differences in sensitivity depend upon whether one systematically moves a small test patch eccentrically along a radius of the visual field, or whether the observer fixates a grating at its center. In the former case, the radial location of the eccentric target is considered as that position on which the center of the target falls. Consequently, the retinal meridian presumably making the visual resolution is taken as the one corresponding to the radial position of the center of the target, regardless of the orientation of the lines within the test patch. Such a procedure produces results similar to detection sensitivity. That is, the horizontal meridian of the retina exhibits best acuity and the vertical meridian shows poorest acuity(8, 9, 10). Regardless of the eccentricity and radial location of the test patch, there are still systematic differences in resolution thresholds for the various orientations of the lines within the circular test patch.

For the case in which an observer fixates the line-grating at its center, the so-called "retinal astigmatism" effect is found(11, 12). That is, the horizontal and

[2]Dr. Shetler was present at the reading of this paper and was kind enough to inform the author that, in fact, the vertical orientations of his target patterns did produce slightly, but not significantly, better performance than the diagonal orientations of the targets.

the vertical orientations of the lines produce about equal acuities, which are greater than those produced by either diagonal orientation of the lines. The diagonal inclinations of the lines exhibit acuity which is about equal to one another. Of course, under such conditions of central fixation all meridians of the retina are stimulated more or less equally by the test object. However, the retinal meridian given credit for the resolution is either the one parallel to, or perpendicular to, the orientation of the lines. By this method of specifying performance the horizontal and the vertical meridians are reported to have equally good acuities and these measured acuities are superior to the acuities reported for the diagonal meridians.

The discrepancy between the conclusions derived from the two experimental situations above, specified in terms of acuity for the retinal meridians, is one of the lines of evidence leading to the present speculation that localization accuracy and detection sensitivity do not produce identical conclusions concerning relative performance among retinal meridians. It is argued that the case of the small patches moved out along the radii produces basically a detection sensitivity task for the retinal meridian stimulated, whereas the larger, centrally-fixated grating involves a radial localization factor.

Accuracy of Radial Localization

A visual task measuring the accuracy of radial localization was employed in an experiment by Leibowitz, Myers, and Grant(13). This experiment, in which stimuli were presented eccentrically under various conditions of luminance and tachistoscopic exposure duration, is of relevance here. Observers were required to judge in which of the 72 possible radial positions (described by 5-degree intervals from above-center) a target had been presented. Localization accuracy was best above, below, left and right of fixation, and poorer on the radii in diagonal directions from fixation. Results from this study and another study by the same authors(14) indicate that, if a target is above detection threshold, then luminance and exposure duration are not variables affecting errors of localization. Of course, luminance and exposure duration are variables affecting target detection.

These radial localization experiments are quite similar to those experiments investigating estimation of bearing. The data from bearing estimations(15) correspond to the predictions made here for radial localization — as might be expected.

A study by Harcum(16) tested the hypothesis that detection and localization of tachistoscopically-presented single black circular targets, or outline circle targets was greatest along the horizontal meridian, and that this perception was poorest along the vertical meridian of the visual field. A target circle was presented along the vertical, horizontal, or one of the two diagonal meridians, and the observers attempted to report the radius on which the target appeared. Under the conditions of the experiment there were only few errors made when the blackened targets were presented. However, of the small number of errors made, more occurred along each of the radii that were diagonal from fixation than for those that were horizontally or vertically displaced from fixation, although these

differences were not significant. For the open circles, in which the overall number of errors was greater, detection-localization accuracy was greatest along the horizontal meridian, and worst along the vertical meridian. Therefore, when the targets are relatively more difficult to detect the detection function relating performance and radial position is seen, and when the targets are relatively easy to detect the localization function is seen.

In a study by Attneave(17) the direction and magnitude of localization errors for a single spot in a large circular visual field, which was without physical reference markers, were analyzed. Again localization accuracy was greatest along the horizontal and vertical meridians, and least in the areas diagonal from fixation. Attneave reports a tendency for the observers to mis-localize targets away from the horizontal and the vertical axes of the field and interprets this result as implying subjective or implicit landmarks in the visual field. He speculates that slight displacement of the target from a landmark would tend to be deemphasized and larger displacement would be exaggerated.

Proposed Factors

Heuristic general descriptions of the results predicted for the localization accuracy factor and the detection sensitivity factor are given in Fig. 1. This

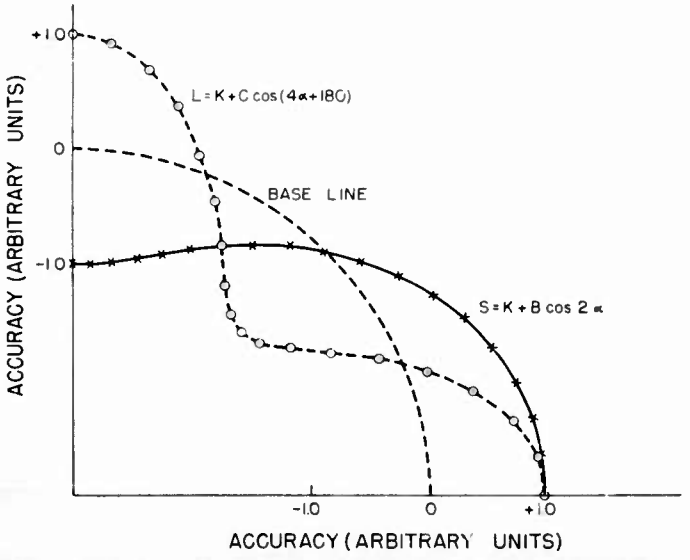


Fig. 1. Illustration of iso-performance contours that might describe the S(sensitivity) and the L(localization) factors, which affect radial localization accuracy for eccentrically presented targets.

figure represents a quadrant of the visual field. The polar coordinates represent an arbitrary scale describing accuracy of performance, with increasing values rep-

resenting increasing accuracy. The localization factor is designated as "L," and the detection sensitivity factor is labelled "S." The radial markers are nominal only and do not refer to the α in the equations, which refers to angles from horizontal. No argument is made concerning whether these curves are the best possible fitting curves, or even adequate fits to the data.

The final results of a given experiment investigating the relative differences among the radii of the visual field reflect the relative importance of the S and L factors for that task, and, correspondingly, the relative magnitude of the amplitude constants of the two curves. The amplitude constant in the sensitivity function first increases and then decreases with target intensity. This occurs because whenever the intensity is very low no targets are detected and, consequently, there are no differences in the accuracy of detection among radii. Whenever the intensity is high enough for all targets to be detected, there are again no differences among the various radii. The amplitude constant in the L factor is monotonically related to stimulus intensity and becomes asymptotic as the probability of detection approaches unity. Obviously, these functions for S and L are in some degree related. If the target is detected, the localization accuracy, it is proposed, is maximum. If the target is not detected, the localization accuracy is, of course, chance, if there are no guessing preferences for some radial positions.

In a single investigation using identical apparatus and observers one should obtain, relatively speaking, performance patterns among radii of the visual field described by the S function when the performance measure concerns detection thresholds, and to obtain patterns described by the L function when the task concerns the average estimation error for radial position of clearly suprathreshold targets.

Data from two similar experiments will be reported.

EXPERIMENT I

In the first experiment the fixation field was a simulated radar scope with luminance of about 0.069 ft-L. Degree markers were placed every 5 degrees and numerals occurred every 10 degrees. Diameter of the scope face was 15 degrees at a viewing distance of 24.5 inches.

Single circular targets, 5 minutes in diameter at a luminance of 0.006 ft-L, were tachistoscopically added to the scope face. Each target appeared at a distance of 5.8 degrees eccentric to fixation on one of the 72 radial positions located every 5 degrees from above fixation. There was a white cross at the center of the scope for binocular fixation.

The observer was instructed to indicate, by saying "yes" or "no," whether or not he saw the target *and* to make his best guess to the nearest 5 degree marker concerning the radial position of the target.

In each experimental session, one target presentation at each radial position and one Vexierfehlen were given in random order, using a target exposure duration of approximately .15 second. In a second block of 73 presentations an exposure duration of approximately .05 seconds was employed. The two exposure

durations were used in order to produce a difficult detection task (that is, with about 50 per cent failures to detect) and an easy detection which produced almost no detection failures.

Two observers each served in nine experimental sessions.

The Critical Sector

In order to differentiate between radial localization errors which were due to failure to detect the presence of the target and those that were due to the failure to accurately localize a target that was detected, it will be helpful to use the notion of the "critical sector." The critical sector is the width in degrees of the sector bounded by the two radii of the visual field which include all estimations of the radial location of a target *provided it is seen*. Consequently, any errors of radial localization outside of the critical sector for the given target radius will be by definition due to a failure to detect the target. Assuming that the observer guesses the radii randomly whenever he does not detect the target, then the guesses outside of the critical sector should be distributed evenly throughout the remaining radii, whether the response is just outside of the critical sector or whether it is 180° in error. Therefore, a critical sector includes those radial positions on both sides of the true locations of the targets in which there is a greater probability of correct localization response than there is for each of the radial locations outside of the critical sector.

The width of the critical sector varies from observer to observer and with certain experimental conditions such as practice in estimating angles and the kinds of reference markers provided. In any case, however, the width of the critical sector should not be expected to exceed, for example, 90 degrees. One would expect the critical sector normally to be a great deal less than that. Such a width of critical sector would mean that the observer, when presented a target directly above fixation at 0°, might localize it as far off as on the radii 315° or 45°.

The critical sector is calculated from the cumulative frequency of localization errors of various magnitudes from 0° to 180°. These errors are the absolute values (in degrees) of the difference between the true radial location and the localization response. Such a tabulation is shown in Fig. 2 for Observer 1 for the two levels of task difficulty. Only cumulative percentages of responses having from 0 to 90 degrees of error are plotted in this slide. Obviously, the final cumulative percentage at 180° must be 100 per cent. The straight lines, visually fitted through the data points at the right, indicate approximately equal numbers of errors in the error categories fitted by the line. The data points at the left in each function which fall above the extrapolation of the line indicate detection of the target. The number of detections at a point can be inferred by the vertical difference between the base line and the data point. For the observer shown in this figure the data points corresponding to 0 and 5 degrees of error fall above the base line for both levels of target difficulty. Therefore, the critical sector for target detection for this observer is taken as bounded by limits of 10 degrees in either direction from the true radial position. Figure 2 suggests that, if the observer could detect the target at all he could localize it accurately within 10 degrees. However, the

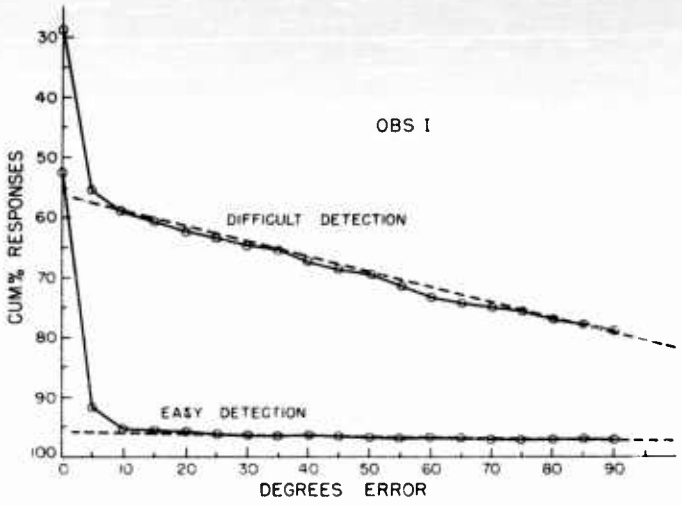


Fig. 2. Cumulative percentages of responses corresponding to the various magnitudes of radial localization error in Experiment I by Observer I. This graph illustrates the calculation of the critical sector for two levels of target detection difficulty for this observer.

width of the critical sector is not always the same for every observer. The corresponding data for a different observer are shown in Fig. 3. This observer shows a critical sector width of ± 20 degrees.

Results of Experiment I

The results of Experiment I are shown in Fig. 4 for Observer I and in Fig. 5 for Observer II. Both sets of data for each observer confirm the predicted result, as do the data averaged for both observers and given in Fig. 6. Detections within the critical sectors are more numerous along the horizontal coordinate of the visual field and the frequency of errorless radial estimations are greater near both the vertical and horizontal coordinates than at the diagonal meridians.

An important phenomenon, which was not unexpected, is the slight increase in localization accuracy at the 45° radii. Apparently the observers can use diagonal subjective reference lines, but not as well as they can use horizontal and vertical ones.

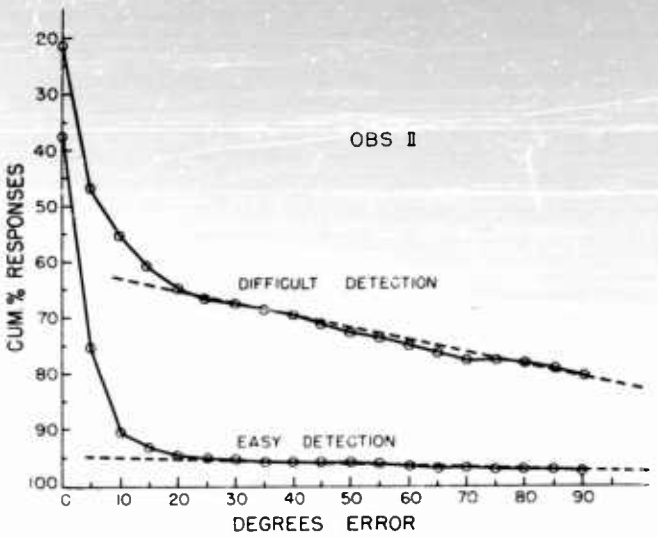


Fig. 3. Cumulative percentages of responses corresponding to the various magnitudes of radial localization error in Experiment I by Observer II. This graph illustrates the calculation of the critical sector for two levels of target detection difficulty for this observer.

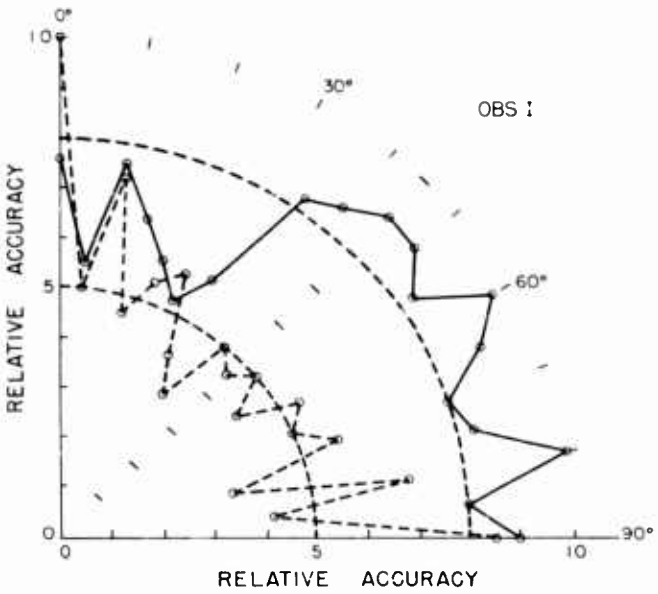


Fig. 4. Target detection and localization accuracy as a function of the radial location of the target in Experiment I by Observer I.

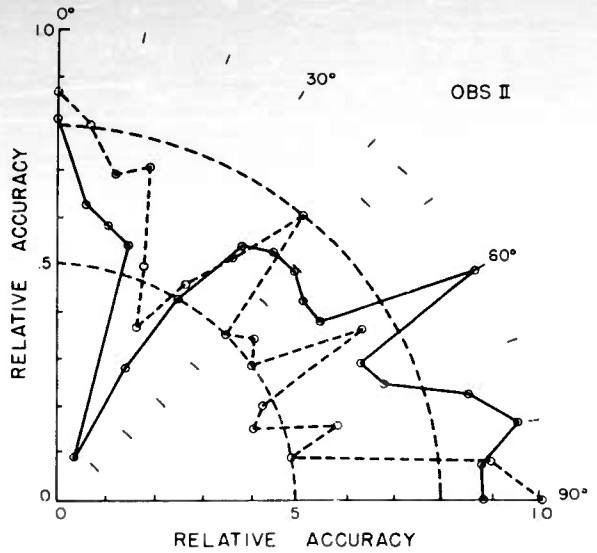


Fig. 5. Target detection and localization accuracy as a function of the radial location of the target in Experiment I by Observer II.

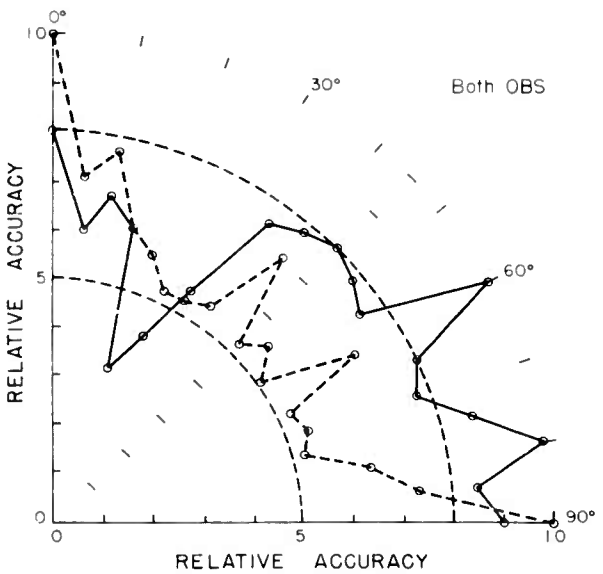


Fig. 6. Target detection and localization accuracy as a function of the radial location of the target in Experiment I averaged for Observers I and II.

EXPERIMENT II

Apparatus and Procedures

For the second experiment to be reported, a flashed opal screen formed the target field. This screen was surrounded by an unmarked circular black mask, which produced a circular field about 10° in diameter. At the center of this field was a black cross which was fixated binocularly. A field luminance of about 0.01 ft-L was provided by indirect lighting. Viewing distance was 10 feet.

Different radial locations of a two-minute target were provided by the different radial locations of a target hole in a large wheel which was rotated behind the opal glass screen. Therefore, whenever a tachistoscope behind the wheel was flashed, the target spot was added to the visual screen for the time interval set on the tachistoscope. An attempt was made to adjust the luminance of the target, according to practice results from each observer, to produce target detections for each observer on about 65 per cent of the observations.

On each exposure a target could appear on any one of 72 radial positions (i.e., five-degree intervals from 0° to 360°), or else no target would appear. Regardless of radial position the target was always eccentric from fixation by 2.4 degrees.

The observer was required to report on each target exposure whether or not he had seen the target *and* his best guess concerning its radial location.

In each experimental session which lasted up to approximately two hours, each of the seven observers completed 20-50 practice observations and 73 experimental observations. The 73 experimental observations consisted of one presentation of a target at each possible position and a no-target presentation, in haphazard order.

Results of Experiment II

The calculation of the critical sector for two typical observers is illustrated in Fig. 7. As one can see, we were not always able to set the task difficulty at 65 per cent detections. This did not appear to affect final conclusions, however.

The final results summarized for all observers are illustrated in Fig. 8. In this slide the 72 radii investigated were combined into eight sectors with nine radii per sector. Each sector is designated by the compass point corresponding to the middle radius of the sector, for example, the north sector. Since the prediction of data made for these studies does not discriminate between sectors exactly opposite each other across fixation, the opposite sectors were averaged.

Three response measures are reported in Fig. 8. The first is average error of localization. The number of cases entering into this average is the number of responses whose localization error *did not* fall outside of the critical sector. In other words, only those observations in which the target was detected entered into the average for the localization error. The results for this measure can be seen to verify prediction. There are fewest errors in the sectors that are horizontal or vertical from fixation, as predicted by the localization factor.

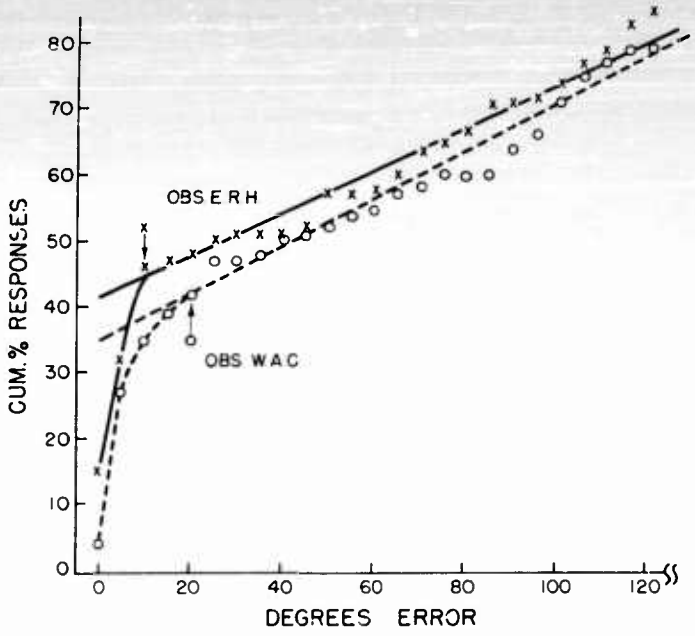


Fig. 7. Cumulative percentages of responses corre nding to the various magnitudes of radial localization error in Experiment II by two typical observers. The arrows indicate the limits of the critical sector for each observer.

One measure of detection sensitivity is afforded by the critical sector. Here the average number of failures to detect the target are plotted. In other words these are the average number of responses outside of the critical sector. As predicted for detection data most failures occur in the vertical sectors and fewest appear in the horizontal sectors.

The second detection measure in Fig. 8 is the average frequency of a verbal report of non-detection. This is merely the average number of times that the observers reported "no" detection for targets in the various sectors. Again most failures to detect appear for targets above and below fixation, and fewest occur for targets to the right and left of fixation.

The key to the different results is, of course, the vertical sectors. For localization functions their performance rivals that of the horizontal sectors, but for detection tasks they are clearly poorest of all sectors.

Discussion

In discussing these experiments one need not plunge into a consideration of the visual mechanisms underlying differential sensitivity of the various eccentric

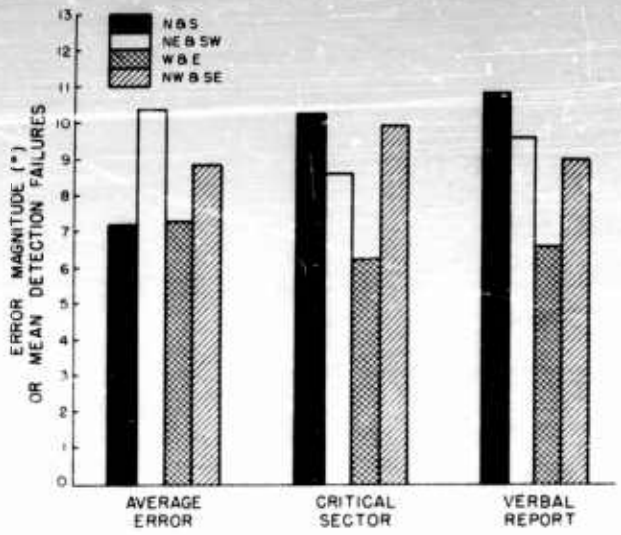


Fig. 8. Target detection and localization accuracy as a function of the radial location of the target in Experiment II averaged for all observers.

areas of the visual field. One speculation is worthy of noting, however, in view of a common phenomenon found in these studies. That is, the observers are hindered in their performance on this task by hallucinated targets. Sometimes the observer "saw" two or three targets on a presentation instead of one, but was allowed to report only one. The author and Miss Ausma Rabe(6) have found evidence that targets are most often hallucinated along the horizontal meridian of the visual field. If this is true, perhaps it is due to a lower criterion level for detection along that meridian because of greater likelihood in everyday experience for targets to appear along horizontal lines. If such an iso-detection contour is the result of learning, one might well speculate that detection of targets above and below fixation could profit from training in lowering the criterion level — if that is desired.

The Localization Factor

Radial localization accuracy might be related to frames of reference in the visual field, as many have suggested. Gibson(18) reports a negative after-effect from previous inspection of a tilted line upon the perceived orientation of a test figure. Perhaps the previous inspection of the tilted line provided a faulty frame of reference which produced a faulty perception of orientation. Most interesting was Gibson's observation that this after-effect on one axis (e.g., horizontal) is accompanied by a corresponding effect on the other (e.g., vertical axis). This indicates the mutual interdependence of the two axes.

Perhaps the accuracy within the N, S, E, and W sectors for radial localization is due to the presence of subjective horizontal and vertical reference meridians in

the visual field. This notion is strengthened by the results of Leibowitz, Myers and Grant(13) and the results of the present Experiment I in that there is a small effect of greater accuracy of radial localization for the diagonal radii (i.e., 45°, 135°, 225°, and 315°) than for those immediately adjacent to them. One of the observers of Leibowitz, Myers, and Grant actually produced best performance for the diagonal meridians.

REFERENCES

1. Sloan, E. L. Rate of dark adaptation and regional threshold gradient of the dark-adapted eye: Physiologic and clinical studies. *Amer. J. Ophthal.*, 1947, **30**, 705-720.
2. Munn, N. L., and Geil, G. A. A note on peripheral form discrimination. *J. gen. Psychol.*, 1931, **5**, 78-88.
3. Renshaw, S. The visual perception and reproduction of forms by tachistoscopic methods. *J. Psychol.*, 1945, **20**, 217-232.
4. Harcum, E. R., and Rabe, A. Visual recognition along various meridians of the visual field: VIII. Patterns of solid circles and squares. *Univer. Michigan Engrg. Res. Inst., Proj. Michigan Rep.*, Dec. 1958, No. 2144-306-T.
5. Harcum, E. R., and Blackwell, H. R. Visual recognition along various meridians of the visual field: XI. Identification of the number of blackened circles presented. *Univer. Michigan Engrg. Res. Inst., Proj. Michigan Rep.*, Dec. 1958, No. 2144-314-T.
6. Harcum, E. R., and Rabe, A. Visual recognition along various meridians of the visual field: III. Patterns of blackened circles in an eight-circle template. *Univer. Michigan Engrg. Res. Inst., Proj. Michigan Rep.*, Nov. 1958, No. 2144-294-T.
7. Shetler, W. L., Berbert, J. H., and Finney, W. J. Some factors affecting the recognition of a linear pattern viewed against a random field. *J. Opt. Soc. Amer.*, 1955, **45**, 903-904. (Abstract)
8. Weymouth, F. W., Hines, D. C., Acres, L. H., Raaf, J. E., and Wheeler, M. C. Visual acuity within the area centralis and its relation to eye movements and fixation. *Amer. J. Ophthal.*, 1928, **11**, 947-960.
9. Aulhorn, E., and Voges, W. Parafoveale Gesichtsfeldgrenzen in Abhängigkeit von der Lage der dargebotenen Konturen (Boundaries of parafoveal visual fields as a function of the position of the contours presented. Trans. by Jeane M. Lotze) *Pflüg. Arch. Ges. Physiol.*, 1953, **257**, 329 342.
10. Wertheim, T. Über die indirekte Sehschärfe. *Z. für Psychol.*, 1894, **7**, 172-187.
11. Higgins, G. C., and Stultz, K. Visual acuity as measured with various orientations of a parallel-line test object. *J. Opt. Soc. Amer.*, 1948, **38**, 756-758.
12. Leibowitz, H. Some observations and theory on the variation of visual acuity with the orientation of the test object. *J. Opt. Soc. Amer.*, 1953, **43**, 902-905.
13. Leibowitz, H. W., Myers, N. A., and Grant, D. A. Radial localization of a single stimulus as a function of luminance and duration of exposure. *J. Opt. Soc. Amer.*, 1955, **45**, 76-78.
14. Leibowitz, H. W., Myers, N. A., and Grant, D. A. Frequency of seeing and radial localization of single and multiple visual stimuli. *J. exp. Psychol.*, 1955, **50**, 369-373.
15. Rogers, S., Volkmann, J., Reese, T. W., and Kaufman, E. L. Accuracy and variability of direct estimates of bearing from large display screens. Psychol. Res. Unit, Mt. Holyoke Coll., *Memo Rep. 166-1-MHCI*, May 1947.
16. Harcum, E. R. Visual recognition along various meridians of the visual field: XII. Acuity for open and blackened circles presented eccentrically. *Univer. Michigan Engrg. Res. Inst., Proj. Michigan Rep.*, in press, No. 2144-315-T.
17. Attneave, F. Perception of place in a circular field. *Amer. J. Psychol.*, 1955, **68**, 69-82.
18. Gibson, J. J. Vertical and horizontal orientation in visual perception. *Psychol. Bull*, 1934, **31**, 739-740. (Abstract)

FACTORS DETERMINING THE IDENTIFICATION OF AMBIGUOUS VISUAL STIMULI*

RICHARD H. HENNEMAN

One of the more serious problems of visual search concerns the difficulty of target or signal detection and identification because of ambiguous stimulus data. Such stimulus ambiguity may arise from several conditions, such as masking, distortion or impoverishment. These adverse conditions, frequently encountered in operational situations, lead to delays and inaccuracies of the perceptual responses of the observers. Since little can be done in most practical situations to reduce the physical sources of stimulus ambiguity, there arises the significant question of whether it may be possible to alter the state of the observer so as to improve his perception under such conditions. To what extent may greater operator proficiency be achieved by providing him with a stock of "built-in" responses, thereby enabling him to act more independently of the physical stimuli? The notion of multiple determination of perceptual responses and the closely related concept of "set" offer suggestive leads toward the answer of this question.

Bearing rather directly on the question is the well established fact that highly trained operators often acquire astonishing proficiency in "translating" garbled target and signal data into meaningful information. The success with which control tower operators and reconnaissance photographic interpreters combat highly ambiguous stimulus data may be cited as specific examples. We may ask, what actually enables these operators to respond effectively in such situations? Do they, with training, acquire greater skill in discriminating distorted or impoverished stimuli, or do they come to rely heavily upon "built-in" responses, largely independent of the physical characteristics of the stimulus? (Or does their behavior reflect an interaction between these two processes?) In familiar situations independent responses may have been introduced into the operator's repertory by differential frequencies of previous occurrence of events; in short, the operator may have learned to respond in terms of probability of stimulus occurrence as well as, or instead of, on the basis of stimulus cues actually present.

There is experimental evidence relevant to these questions. The studies relating word frequency in the English language to recognition thresholds support the importance of the role of differential frequency of stimulus occurrence in perception. It has been further demonstrated that recognition of tachistoscopically exposed nonsense syllables is significantly related to their respective frequencies of previous presentation. In the logical ultimate to this type of experiment, Goldiamond and Hawkins(4) have recently shown that subjects report having "seen" nonsense syllables during very brief exposures, as a direct function of their frequency of previous presentation, even when no words were presented during the test session.

*This study was conducted under Contract No. DA-49-007-MD-537, with the Office of the Surgeon General of the Army.

The numerous experimental studies relating to the influence of motivation and "set" upon perception (while they have led to considerable disagreement of interpretation) afford additional evidence that subjects' responses to ambiguous stimuli can be manipulated independently of the stimulus patterns. For example, E. R. Long, L. S. Reid, and the author of this paper, defined "set" as a restriction of the subjects' stock of potential responses. They were able to demonstrate greatly increased "intelligibility" of ambiguous letters and words, presented visually, by progressively reducing the number of response alternatives available to the subjects(5).

Eriksen(2), in reviewing the literature relating to discrimination without awareness, interprets the results of these studies as evidence that responses can be induced in the observer which are independent of the discriminative stimuli presented. Goldiamond(3), in a similar review of the literature pertaining to subliminal perception and unconscious perception, suggests that many measures used as indicators of perception, may be largely independent of the physical stimuli. He concludes that the subject ". . . tends to respond in terms of consequences of his response and in relation to other nonperceptual variables. . . ." It thus seems to be widely accepted that an observer's perceptual responses can be influenced by factors other than the stimulus data, when physical conditions have rendered these latter ambiguous. There are numerous conditions which can produce these influences, such as situational context, previous training, special instructions to the observer, etc.

A persistent and as yet unsettled question involves the identification of those variables that determine which of various responses in the total perceptual process are in fact influenced by these special conditions. More specifically, what are the variables that actually influence the observer's discrimination of the stimulus cues, and which variables merely modify the verbal judgments that he makes? Neisser(6) has stated the question in this way: does the observer learn to see differently or to say differently in learning to identify ambiguous stimuli? Available experimental evidence seems to indicate that sometimes he "sees" differently, and under other conditions, merely "says" differently. We need a better understanding of the specific antecedent conditions of the "seeing" or the "saying," if the principle of independent perceptual responding is to be applied to the process of visual search.

A recent experiment at the University of Virginia (which was planned before the publication of the reviews by Goldiamond and Eriksen) was designed to explore some of the possibilities raised in the above discussion. It was sought to learn whether, in identifying distorted visual patterns, subjects can be increasingly influenced by differential frequencies of stimulus presentation, as the patterns become progressively more distorted, hence more ambiguous. In other words, do subjects come to reflect, in their identification responses, the differential probabilities of previous stimulus occurrence rather than the physical properties of the stimuli themselves? It was also desired to learn whether, with continued practice in identifying these distorted stimuli, the subjects improve their discrimination of the stimulus cues, or tend to rely more and more on the independent

responses derived from differential frequency of previous occurrence. It is obvious that in such an experiment both the number and nature of the identification errors are important. Kind of error should indicate which experimental variable is most influencing the subject's responses under a given condition (i.e., stimulus cues or probability of occurrence). The hypothesis to be tested called for the subjects to make more errors at higher levels of stimulus distortion, and for these errors to reflect the more frequently presented stimulus patterns.

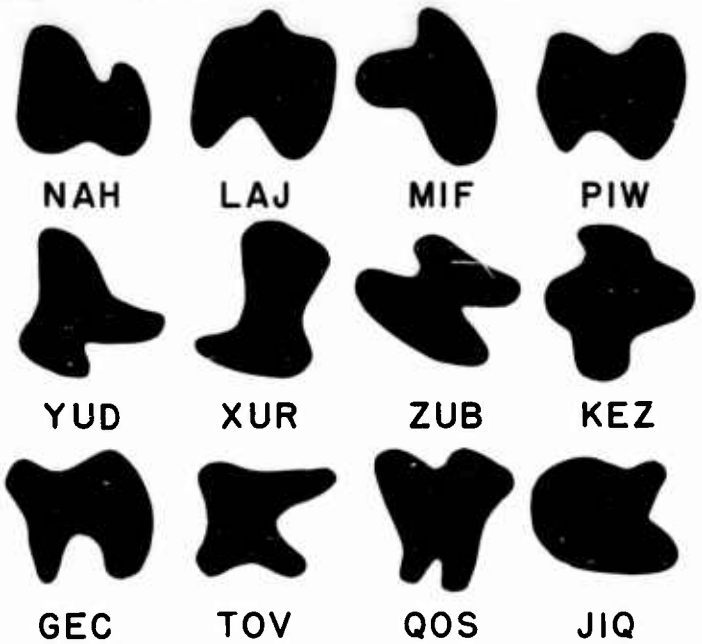


Fig. 1. The twelve stimulus forms and nonsense syllable labels.

Stimulus materials consisted of 12 nonsense forms, patterned after Boynton's "struniforms"(1). Each form was labelled with a nonsense syllable of low association value. The 12 forms and their associated nonsense syllables are shown in Fig. 1. Stimulus distortion was achieved by a combination of three reproducible manipulations: (1) exposure time, (2) contrast between the form and its background, and (3) "defocusing." A Clason Acuity Meter was fitted with a slide rack and a Wollensak "Alphax" shutter to vary exposure time and defocusing. The forms were photographed with various contrast levels and slides were made from the prints. Defocusing was manipulated by adjusting the acuity meter which had a finely graduated scale. Various combinations of exposure time, contrast, and defocusing were tried out in a preliminary test to determine three levels of distortion for the experiment proper. The three selected levels of distortion were achieved by using a single exposure time (.01 sec), two contrast levels, and three

degrees of defocusing. These three levels were labelled respectively "slight" (70 per cent successful identification); "moderate" (45 per cent identification); and "severe" (15 per cent identification).

In a preliminary session the subjects learned to "label" each of the 12 forms with their respective associated nonsense syllables. In the experiment proper the successive forms were presented on a screen, one at a time, without labels, and either undistorted, or at one of the three distortion levels noted above. The subjects were required to spell out the identifying syllable immediately following stimulus presentation, and to guess when in doubt. After each identification, subjects were shown the correct label (nonsense syllable) to provide "knowledge of results." The twelve forms were subdivided into three groups of four forms each for differential frequency of presentation, in the ratios of 1 to 3 to 6. The forms of all three frequency groups were presented at all four levels of distortion. Each experimental sequence included a total of 160 presentations (four presentations of the low-frequency group, 12 presentations of the intermediate-frequency group, and 24 presentations of the high-frequency group, at each level of distortion). Presentation for a given sequence was randomly ordered with the one restriction that no form could follow itself. Six sequences were drawn up so as to counterbalance completely the form-group x frequency factor. One male undergraduate college student was randomly assigned to each sequence. Each subject was tested with the same sequence (but with order reversed) for three successive days. On the fourth day each subject viewed the mirror-image reversal of the first day's sequence, i.e., the high-frequency forms were drawn from the original low-frequency group and vice versa.

The experimental design thus called for three frequencies of presentation and four levels of stimulus distortion. The experimental variables were manipulated for analysis of within-subjects variance. Since the subjects returned for three additional sessions beyond the first day, the influence of practice might also be expected to show up in the scores of the successive sessions. It was hoped that the number and kind of errors for the various conditions would reveal the interrelation among the three variables, stimulus distortion, frequency of presentation, and practice, as determiners of the perceptual identification of ambiguous stimulus patterns.

The errors under the various conditions of the experiment were analyzed for the effects of four main factors (Subjects, Distortion, Kind of Error, and Frequency of Presentation). The statistical analyses were done separately for the four sessions, and with the data grouped for the first three sessions. The detailed analyses are omitted from the present paper for purposes of brevity. Table 1 summarizes the errors for three distortion levels and the first three sessions. (Data for the undistorted condition and Session IV are omitted.)

The results, although not completely unequivocal, suggest the following generalizations:

1. Identification becomes increasingly difficult as the stimulus forms become progressively more distorted. The analysis indicated a significant

TABLE 1

ERRORS UNDER VARIOUS EXPERIMENTAL CONDITIONS

Distortion Level

Frequency of Presentation		"Slight" Distortion Kind of Error				"Moderate" Distortion Kind of Error				"Severe" Distortion Kind of Error			
		.1	.3	.6	Tot	.1	.3	.6	Total	.1	.3	.6	Total
p. 1	Session I	0.00	2.00	2.00	4.00	3.00	5.00	8.00	16.00	3.00	10.00	10.00	23.00
	II	0.00	2.00	0.00	2.00	0.00	4.00	5.00	9.00	2.00	12.00	6.00	20.00
	III	0.00	1.00	1.00	2.00	3.00	2.00	2.00	7.00	3.00	11.00	10.00	24.00
	Mean	0.00	1.67	1.00	2.67	2.00	3.67	5.00	10.67	2.67	11.00	8.67	22.33
p. 3	Session I	2.67	1.66	1.33	5.66	5.00	2.99	4.99	12.98	4.67	6.32	10.67	21.66
	II	0.33	0.33	1.00	1.66	1.99	2.00	2.32	6.31	4.67	6.01	8.34	19.02
	III	0.33	0.00	0.33	0.66	0.33	1.00	2.33	3.66	3.98	5.99	9.00	18.97
	Mean	1.11	0.66	0.89	2.66	2.44	2.00	3.21	7.65	4.44	6.11	9.34	19.88
p. 6	Session I	2.50	1.34	0.67	4.51	4.66	4.01	2.00	10.67	6.67	5.51	7.00	19.18
	II	0.67	0.34	0.00	1.01	0.67	3.83	1.50	6.00	2.67	7.16	5.67	15.50
	III	0.33	0.34	0.17	0.84	1.17	2.84	0.83	4.84	2.68	5.67	6.83	15.18
	Mean	1.17	0.67	0.28	2.12	2.17	3.56	1.44	7.17	4.01	6.11	6.50	16.62

Summary table of errors made by six subjects under three conditions of stimulus distortion, arranged by "Kind of Error," Frequency of Presentation, and Session. Data of Session IV not included. The totals indicate number of errors made in 24 identifications. These data have been corrected for differential frequency of presentation.

main effect of distortion. The general effect of distortion is indicated graphically in Fig. 2.

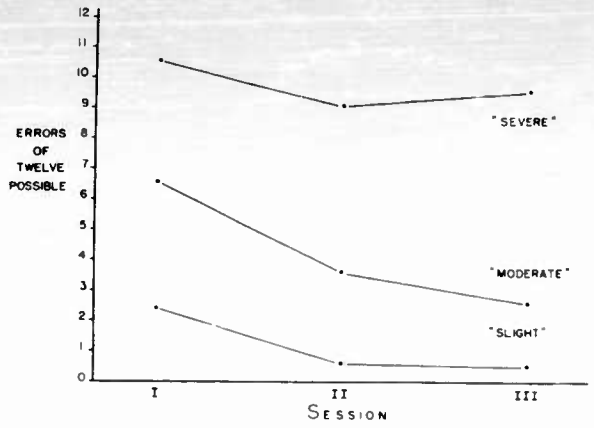


Fig. 2. Kind of Error as related to degree of stimulus distortion. The data of Table 1 have been regrouped and averaged. Results from the non-distorted condition have been added for comparison.

2. Errors are significantly related to distortion level and to frequency of stimulus occurrence, as indicated by a consistent Distortion by Kind-of-Error interaction. This trend is discernible from inspection of the table, though the various conditions do not differ with complete consistency. These data are shown graphically in Fig. 2.

3. There is evidence that the subjects improve their identification with practice (i.e., fewer errors are made at successive sessions). This practice effect is more marked for the "moderate" than for the "severe" and "slight" distortion levels, as had been predicted. These effects are shown graphically in Fig. 3. These results seem to indicate that there are too few errors made at the "slight"distortion for much improvement to occur, whereas the distorted stimulus cues at the "severe" level do not provide an adequate basis for improvement of identification.

While only moderately suggestive, there is some evidence that practice has a different effect on kind of errors under the "moderate" and "severe" conditions of distortion. Under "moderate" distortion there is some trend away from "high-frequency" errors toward errors reflecting confusion among the 12 competing patterns, whereas under "severe" distortion the effect of differential frequency of occurrence becomes perhaps even more pronounced from Session I to Session III. These error trends suggest that subjects can improve their discrimination only when the stimulus cues are at least partially recognizable. Further investigation is required to confirm such an hypothesis and to learn more precisely the influence of these two sources of error as related to practice. In one such experiment, sim-

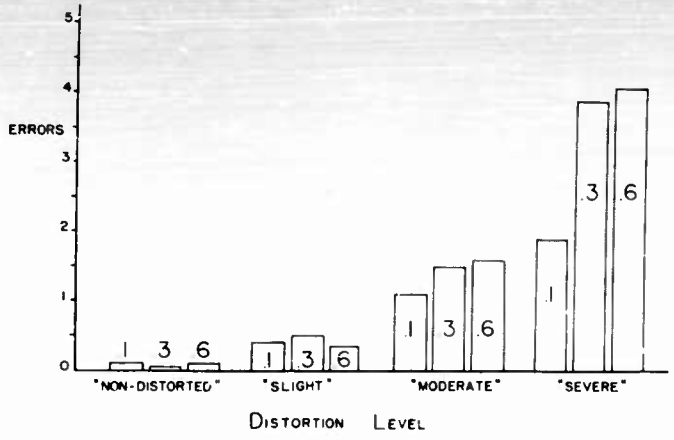


Fig. 3. Average errors per subject by session for each distortion level.

ilarity among stimulus patterns might be made a variable so that the influence of similarity among competing stimuli could be compared with that of differential probability of occurrence. Error analyses of this kind might be expected to shed considerable light on the nature of the perceptual process (e.g., on the relative roles of the processes of "discrimination" and "judgment").

REFERENCES

1. Boynton, R. M. Recognition of critical targets among irrelevant forms. In *Form discrimination as related to military problems*. Washington, D. C.: National Academy of Sciences–National Research Council Publ. No. 561, 1957. Pp. 175-184.
2. Eriksen, C. W. Unconscious processes. *Nebraska Symposium on Motivation*, 1958, 169-227.
3. Goldiamond, I. Indicators of perception: I. Subliminal perception, subception, unconscious perception: An analysis in terms of psychophysical indicator methodology. *Psychol. Bull.*, 1958, **56**, 457-463.
4. Goldiamond, I., and Hawkins, W. F. Vexierversuch: The log relationship between word-frequency and recognition obtained in the absence of stimulus words. *J. exp. Psychol.*, 1958, **56**, 457-463.
5. Long, E. R., Henneman, R. H., and Reid, L. S. Theoretical considerations and exploratory investigation of "set" as response restriction. *USAF WADC tech. Rep.*, 1953, No. 53-311.
6. Neisser, U. An experimental distinction between perceptual process and verbal response. *J. exp. Psychol.*, 1954, **47**, 339-402.

FROM RECOGNITION, SPATIAL ORIENTATION, PERCEPTION OF MOVEMENT IN THE UNIFORM VISUAL FIELD*

WALTER COHEN

The natural habitat of the human organism provides a visual world which is highly structured. Thus, through a process of evolutionary development and learning, the individual experiences and evaluates events in the world on the basis of the stimulus gradients present in his visual field. In most instances, these stimulus gradients (gradients of intensity, chromaticity, as well as texture) are distributed throughout the entire visual field. There are, however, situations in which such gradients are absent, and the distribution of stimulation in the visual field is relatively uniform. (This condition exists for military personnel who are required to search for and recognize objects in the fog, snow, and sky.) The research to be summarized in this report is concerned with perception in such a uniform field.

In order to investigate this problem, it was necessary to develop apparatus which produced a completely uniform textureless field (homogeneous Ganzfeld) in which simple figures could be presented. A modified photometric sphere having a diameter of 1 m. was constructed and provided a completely uniform field. A specially designed mask, which functioned as a headrest, permitted unobstructed monocular viewing of the entire visual field. A detailed description of this apparatus has been published(1). Several papers dealing with the function of stimulus gradients in determining the phenomenal characteristics of the Ganzfeld are also available(1, 2, 3).

Homogeneous Ganzfeld

The most characteristic description of the homogeneous Ganzfeld was that of an impenetrable fog. The phenomenal space and distance of this field were indefinite, and the subjects had great difficulty in describing their experiences. The terminology ordinarily used in the description of the visual world seemed inadequate.

After prolonged exposure to a uniform field, many subjects reported an experience of "blanking-out." This "blanking-out" phenomenon can perhaps best be described as a temporary cessation of vision. There are, however, various degrees of "blanking-out." For instance, the subject may report simply having a feeling of light with no external reference. In other instances, the subject may report "not seeing anything." In the more extreme phase of the phenomenon, which usually occurred only after prolonged exposure of 10 to 20 min., there was a "complete absence of seeing." In the last instance, the subjects were not only completely unaware of vision as a sense modality but seemed to lack feed-back from their eye muscles. They often reported that they were uncertain as to whether or not their eyes were open and were not capable of voluntarily controlling their eye

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movement. Although blinking and eye movements usually were sufficient to bring about a return of the visual field during most "blank-out" experiences, this was not true for the more extensive loss of vision.

Persistent uniform stimulation in the absence of structure seems to result in the failure of the perceptual mechanism to produce a phenomenal field. This temporary breakdown of the visual mechanism is further indicated by an analysis of EEG records obtained during uniform stimulation. Reports of "blank-out" were found to be associated with the return of bursts of alpha activity. Since alpha pattern in the EEG record is usually associated with the absence of visual stimulation, the return of alpha during "blank-out" would indicate a functional similarity between no stimulation and prolonged uniform stimulation. It is interesting to note that individual differences existed in the susceptibility to "blanking-out" and that the susceptibility was correlated with the individual's EEG records. Thus, those subjects exhibiting a high alpha index in the absence of any visual stimulation were more susceptible to "blanking-out" than those exhibiting a low percentage of alpha activity.

After a 20 min exposure to the field, a variety of after-effects were observed. The subjects reported extreme fatigue along with a feeling of great lightness of body. Their motor coordination was poor and they were unable to maintain balance. Their perception of time was disturbed. They often complained of dizziness and behaved in an extremely giddy, almost drunken manner. One subject even reported suffering from temporary states of depersonalization. These effects are similar to those observed under much longer periods of sensory deprivation.

Form Recognition

If the "blanking-out" represented a temporary breakdown of the visual mechanism, it seemed almost inevitable that the capacity of the organism to make discriminations during a "blank-out" would be greatly interfered with. In order to study this problem, 2.5 cm geometric outline figures were projected at eye level onto the wall of the sphere to the right of the subject. The distance between the target and the subject was approximately 75 cm. In this instance, the mask, which served as a head-rest, was tilted so that the target was directly in the subject's line of sight. A series of 16 figures ranging in complexity from a circle to a star was used. The figures were presented tachistoscopically for $\frac{1}{25}$ sec. The time of the presentation coincided with the subject's signals of "blank-out" and "no blank-out."

The less complex figures were usually correctly identified during the "no blank-out" periods. However, in no instance was the subject able to recognize any of the figures during "blank-out." This was true even for the successive presentation of the same figure during the "blank-out." At best, the subjects could only report a "flash." No experience of form occurred under these conditions. The presence of the figures, however, did seem to terminate the "blank-out" in many instances. During the more intensive type of "blank-out," the introduction of the figures into the field for such a short duration seemed to have no effect whatsoever. Not even a "flash" was experienced. Longer duration of figure exposure

(2 sec) brought about the termination of this type of "blank-out" as well. There were indications that even during the "no blank-out" period those subjects having a high alpha index were less accurate in form recognition in the uniform field than those subjects with a low percentage of alpha activity.

A study was designed to investigate the effects of the following variables upon the accuracy of form recognition: (a) the structure of the visual field, (b) the structure of the target, and (c) duration of exposure to the uniform field.[1] Each subject was tested with the entire series of 16 figures under each of the following experimental conditions:

Condition UA (uniformity with adaptation) — The subject was exposed to the uniform field for 90 sec and then tested.

Condition UN (uniformity with no adaptation) — the subject was tested in the uniform field with no adaptation period.

Condition DN (differentiation with no adaptation) — The monocular field in this instance was only partially uniform. The central area of the field in which the figure was presented was identical to that of the two previous conditions, but the peripheral area of the field was structured.

Each figure was exposed for 1/100th sec, with an interval of 10 sec between exposures.

The results indicate that form recognition is interfered with by a 90 sec exposure to the uniform field. The extent of this interference is somewhat decreased by the presentation of the series of figures. Thus, the accuracy of recognition for the first two figures of the series is much lower than the accuracy for the remaining 14. The presentation of a figure into the uniform field for even 1/100 sec tends to overcome the detrimental effects of the prolonged uniform stimulation. (The results of additional research indicate that this facilitating effect does not occur when the interval between presentation of figures is extended from 10 to 30 sec.)

The 16 figures were grouped into 3 categories on the basis of accuracy recognition. Those most readily recognized (Group 1) were the circle, square, diamond, equilateral triangle, and right triangle. Those moderately difficult to recognize (Group 2) were the rectangle, parallelogram, the letter T, the letter L, and the inverted letter T. Those most difficult to recognize (Group 3) were the star, pentagon, hexagon, octagon, cross, and the letter X. It should be noted that the detrimental effects of the uniform field are most pronounced in the recognition of the more difficult figures. There was little difference in the accuracy of recognition of the simpler figures (Group 1) under the UN and DN conditions. It was primarily with the more difficult figures that a deficit occurred. The prolonged exposure to the uniform field reduced the accuracy of recognition for all figures. There was, however, a much greater loss in accuracy of recognition of complex figures.

[1]This study was conducted by S. Goldberg under the author's supervision.

Perception of Movement and Spatial Orientation

A stationary figure presented in the Ganzfeld tends to be unstable. Blurring of contours, transformation of shape, as well as disappearance of the figure are reported. In addition, the figure does not appear to be stationary. Autokinetic movement is often reported. The extent of this movement appears to be related to the shape of the figure being observed. However, it is not dependent upon the nature of the gradients producing the figure.

When objects are slowly rotated in the uniform field, the subjects are found to be relatively insensitive to this real movement. In fact, at near threshold speeds, movement is often perceived in the direction opposite to the real movement. This effect is extremely confusing to the subject who finds that the phenomenal displacement of the object is in a direction opposite to that of his experience of its movement. Although the general problem of the perception of real movement in the uniform field will be more systematically investigated, the data now available suggest that, in the absence of an adequate visual framework, there is considerable inaccuracy in the judgment of movement.

A study of the perception of spatial orientation in the uniform field is now in progress.[2] This experiment involves the rotation of objects at a subthreshold speed both inside and outside the Ganzfeld. The results thus far obtained indicate that there is a reduction in the sensitivity to changes in orientation of objects in a uniform field. The extent of this reduction is dependent upon the complexity of the target as well as upon the instructions given to the subject. In addition, the loss in sensitivity to changes in orientation is greater for objects that are already tilted as compared to those that are initially in the vertical position. In the absence of an adequate visual framework, the individual seems to be capable of adjusting objects to the vertical position with a high degree of accuracy but shows a decrease in sensitivity to changes in orientation from the vertical.

Some Implications of the Research

Although the research described was not primarily directed toward developing techniques for the facilitation of visual search in a uniform field, some of the findings seem relevant to this problem.

Since relatively brief exposures to the uniform field are far less detrimental to perceptual accuracy than prolonged exposures, an attempt should be made to minimize the duration of exposure to the field. Some device which permitted periodic differentiation of the field might prove to be useful. Another possibility would be to train the observer to blink frequently and look away from the field whenever possible.

There are considerable individual differences in the susceptibility of individuals to the interfering effects of the uniform field. It may therefore be possible to select personnel who show minimal interference. A battery of per-

[2]This study is being conducted by D. Tepas under the author's supervision.

ceptual tasks and physiological measurements could probably be developed for this purpose.

REFERENCES

1. COHEN, W. Spatial and textural characteristics of the Ganzfeld. *Amer. J. Psychol.*, 1957, **70**, 403-410.
2. COHEN, W. Color perception in the chromatic Ganzfeld. *Amer. J. Psychol.*, 1958, **71**, 390-394.
3. COHEN, W. Apparent movement of simple figures in the Ganzfeld. *Percept. mot. Skills*, 1958, **8**, 32.

OCULAR ACTIVITY IN VISUAL SEARCH

C. T. WHITE and A. FORD

A program of research regarding ocular activity in visual search may logically be divided into three parts:

(1) The study of inherent patterns of activity;

(2) A study of the effects of training or special instructions on such activity patterns; and

(3) The redesign of visual displays, or the restructuring of the field of search to take advantage of these natural activity patterns.

The titles of the papers scheduled for presentation at this symposium would seem to indicate that all three of these aspects of the problem will be discussed to some extent.

The first phase of this program of research, the study of inherent patterns of activity, is, of course, basic to all the rest. What kind of information do we want to obtain in this regard? In the first place, it becomes quite clear on analysis of the problem that we are primarily interested in the fixations, and not in eye movements as such. We want to know the number of fixations per unit of time, and the duration of such fixations. From these two factors a measure of the percentage of time the eyes were fixated can be calculated, this representing a rough estimate of the time during which target detection could occur. Data regarding the rate and duration of fixation, or the percentage of time fixated, are not too meaningful, however, without some indication of the distribution of those fixations in the field of search. The path of the eye-movements, and the distance between successive fixations are two more pieces of information which could be obtained, and which would help to describe more fully the activity patterns of the eye.

Now that we have determined what types of data we would like to obtain, we next must decide on the details of the search situations that should be studied in order to obtain as complete a picture of the problem as possible. In other words, what are the factors that determine how a subject will search in a given situation? The shape and the extent of the field of search are two factors which will obviously influence search activity, especially the spatial distribution of the fixations — and probably in other ways as well.

The internal characteristics of the field of search will have a profound influence on how a person searches in that field. The method of scanning an empty visual field, for example, will be different from that utilized when the field is cluttered with extraneous objects. This, of course, complicates the matter in another way, since different visual tasks are involved, in the one situation it might be thought of as simply the detection of an object, while in the other case a discrimination must be made between significant and non-significant objects. It seems most likely that the major differences between the search activity patterns in the empty and the complex fields of search would be in regard to the rate and

duration of the fixations, with higher fixation rates and shorter durations being associated with empty field search, and lower rates and longer durations with the complex visual field situations.

Certain visual displays have dynamic characteristics which will have an influence on the behavior of the eyes. A radar PPI presentation is a good example of this. The presence of the rotating sweep line, and the relationship this bears to the emergence of targets, makes this a very different field of search than a static display having the same shape, size, and level of background complexity. This characteristic is, therefore, another important factor to be considered in our study of ocular activity in search.

The factors listed above are not all those that could affect search behavior, but this is probably complete enough to provide a framework on which to place the data as they accumulate.

An approach to this problem has been made at the Navy Electronic Laboratory's bioelectric research facility. In this work the electro-oculographic (EOG) technique is being utilized. This technique takes advantage of the fact that a potential difference exists between the front and back of the eye (the corneo-retinal potential, or ocular resting potential). Electrodes are placed above and below each eye, and at the temporal side of each eye. The cornea is positive relative to the back of the eye, so as the cornea approaches or recedes from a given electrode the electric field at the site of that electrode becomes more or less positive accordingly. By means of appropriate DC amplification and recording, it is possible to obtain records of the horizontal and vertical components of the eye movements. In the work being done at NEL these two components are recorded on separate channels of an ink oscillograph, and are also fed into the X and Y inputs of a DC oscilloscope so that a two-dimensional record of the activity may be obtained. The technical details of this work have recently been published elsewhere(2, 3), so no more will be said about it at the present time.

This method of eye-movement recording was chosen because it interferes less with the normal activity of the eyes than any other method, and can be used at any degree of illumination, including total darkness if such is desired. Figure 1 shows a subject with the electrodes in place. The method of electrode attachment shown is only one of a number which were tried. The proper preparation of a subject takes considerable time — to attain the optimum resistance levels, etc.; but once the electrodes are in place the subject readily adjusts to them and can wear them without discomfort for many hours.

The electro-oculographic technique has one definite shortcoming which should be mentioned before we go any further. It does not always provide an accurate record of the path taken by the eyes in going from one fixation to another. The records of the fixations themselves are quite satisfactory, however, and since it is really the fixations which concern us, this doesn't turn out to be of any great importance. It must be remembered, however, that it would be futile to attempt to use this technique for the analysis of movement as such. The source of the error in this situation is an artifact that frequently appears in the vertical

Fig. 1. One method which has been used for the attachment of the electrodes around the subject's eyes. Because the job of making the plastic mask is quite involved, it is not warranted unless you need to place the electrodes at exactly the same positions each time the subject is used. In most cases the electrodes are simply attached with plastic electrical tape.

component of the records. When upward movements of the eyes are made the records usually indicate that the eyes overshot the new fixation rather badly, and then returned to it. Investigation of this, however, showed that this does not faithfully represent what the eye is doing. The electrodes which are located over the eyes appear to be picking up a transient surge at the onset of the upward movement. In monophasic recording, with only the lower electrodes being used, this apparent overshoot is greatly reduced, or eliminated altogether. Figure 2 illustrates this, and also shows an eye blink. Our best guess is that this artifact is due to an incomplete blink reflex which may be associated with sudden upward movement of the eyes.

The artifact just described, and the efforts which have been made to eliminate it, are discussed in detail in a forthcoming article by Ford(1). Work done on this problem since this report by Ford was written has shown that the vertical component indicating eye position, as given by the EOG, is a function of the degree to which the upper and lower eyelids are separated. This appears to be simply a matter of conductivity — as the upper lid approaches the front of the

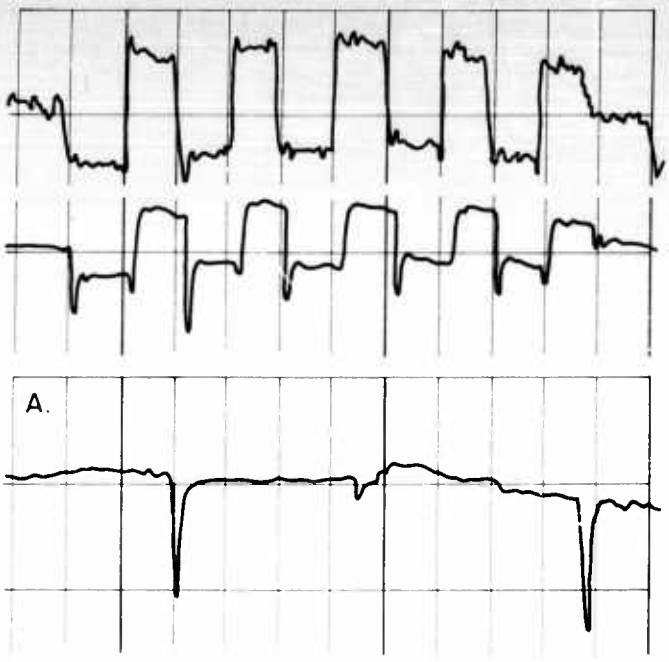


Fig. 2. Examples of the vertical component. The subject was alternately fixating two points separated by 30° in the vertical plane. The top example shows "monophasic" recording — with no electrode above the eyes. The center example is of a "diphasic" recording. Note the apparent overshoot on the upward movement. (An upward movement is represented by a downward movement on the oscillograph.) The bottom example shows how eye-blinks affect the record.

cornea (as during a blink) the resistance between the front of the cornea and the electrode located over the eye is markedly decreased, and the vertical record changes in the way it would if the eyes had moved upward. During a blink the eyes *do* move upward, so the record given by a blink is a result of the increased positivity of the upper electrode brought about by both these factors — upward movement of the eyes, and downward movement of the upper lids. If a partial blink is usually associated with sudden upward movement of the eyes, as we are rather certain is the case, the override artifact can be accounted for. We plan to check this hypothesis in the immediate future. In any case, it is clear that the EOG is not suitable for all types of eye-movement work. Even with this limitation, however, it is possible to obtain all the information listed earlier as being necessary and sufficient to describe ocular search activity.

The first study on visual search made with this technique had limited objectives, since it represented a shakedown trial for the system. The characteristics

of the field of search were as follows: circular, subtending a visual angle of 30°; empty field, no internal dynamics. The subjects were instructed to search for a target that could appear at any position in the field, at any time during the time allotted for search (in this case 5 seconds). Continuous ink oscillographic records were obtained for the vertical and horizontal components, and each 5-second search period was recorded on a separate frame of motion-picture film from the two-dimensional oscilloscope display. Details regarding the running of this study, and a description of the methods of calibration and data reduction can be found in the article to which reference was made earlier(3). For the present purpose a brief resume of the findings would be more to the point.

Data regarding the rate and duration of fixations were obtained from the ink oscillographic records. Figure 3 shows the frequency distribution of fixations

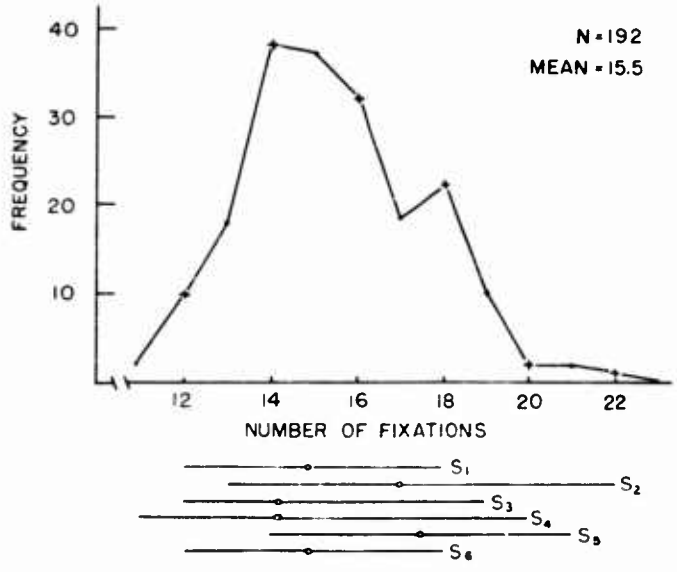


Fig. 3. The frequency distribution of the number of fixations made by subjects during 5-second searches in a 30° circular empty field. Note that mean fixation rate is 3.1 per second.

made during the 5-second search periods by our six subjects. It can be seen that the mean value was approximately 3 per second, the distribution ranging from about 2 to 4 per second. Figure 4 shows the distribution of fixation durations. A sample of one hundred fixations was measured at the beginning and another sample of one hundred was measured at the end of each subject's search session. No significant differences were found between these two samples, so they were combined for this distribution. All measures of central tendency are seen to be at values slightly greater than 0.2 second.

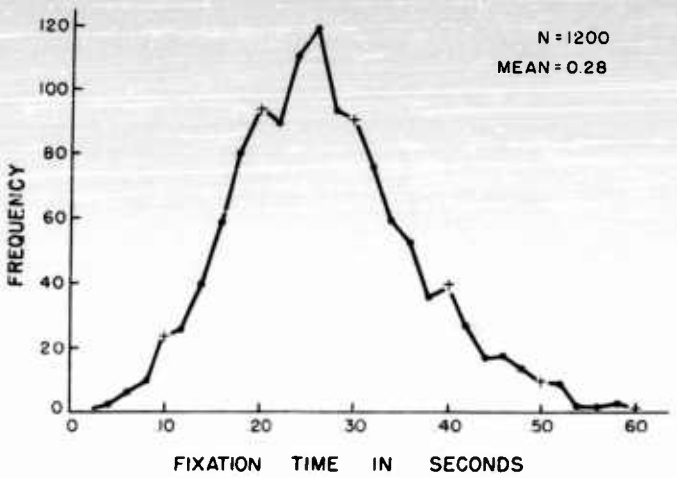


Fig. 4. The frequency distribution of fixation durations for the "free search" situation described in the text.

The two-dimensional film records yielded data regarding the distance between sequential fixations, and the spatial distribution of the fixations. Figure 5

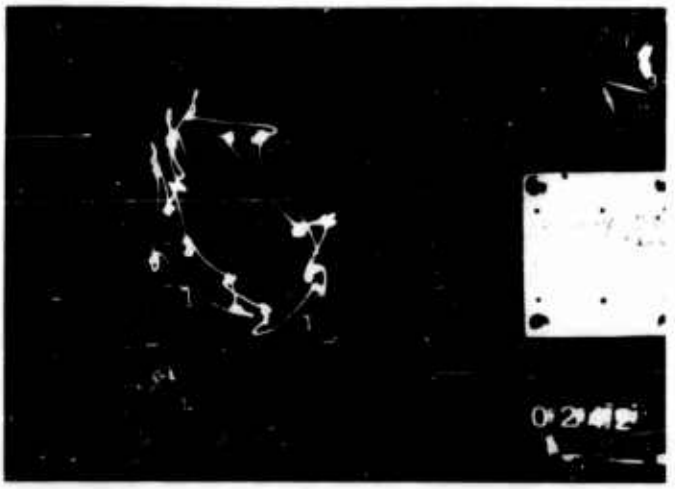


Fig. 5. An example of the ocular activity during a 5-second search period in the "free search" situation.

is typical of the search patterns carried out by the subjects during the 5-second search periods. Figure 6 shows the distribution for all subjects of values of angular

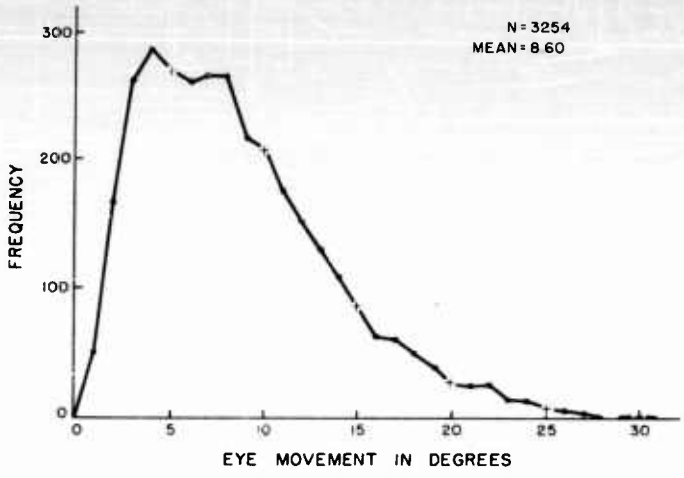
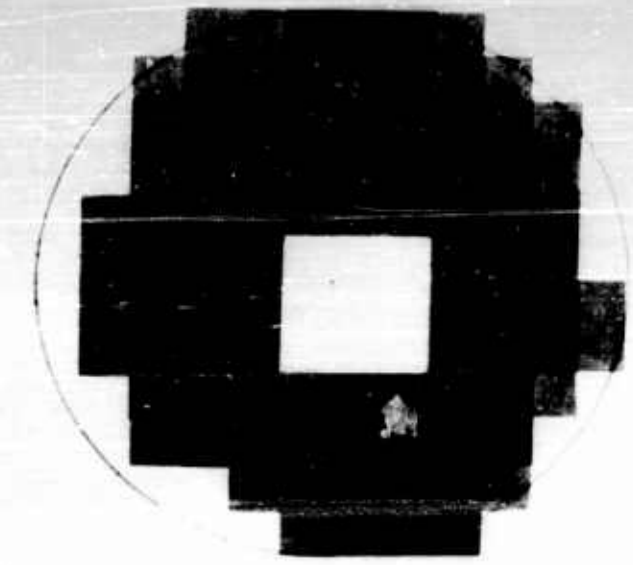


Fig. 6. Frequency distribution of the length of eye-movements, in degrees of visual angle, between sequential fixations in the study described.

distance between fixations. Remember that the extent of this field of search was 30°, and that the field was empty. Changes in field extent and complexity would change this distribution markedly. The very high frequency of values around 4° to 5°, however, seems to indicate that the peak might still remain in this region under other circumstances. The spatial distribution of the fixations made by the subjects in this study is shown in Fig. 7. Only very general statements can be made about such an item, since it is self-explanatory. It is obvious that the subjects did not distribute their fixations evenly over the field of search, although it was made clear to them that the targets could appear anywhere in the field with equal probability. The other thing to be seen is that the center region and the periphery did not get their share of the fixations, these being concentrated in a roughly circular band about half-way between the center and periphery.

The next study attempted was that of search in a simulated radar situation. This is not too appropriate to the business at hand, but it does fit in with the framework for research which was mentioned earlier. In this case this field of search was circular, with an extent of 30° or 15°, empty (noise-free), and with an internal dynamic feature — a sweep line making a revolution in about eight seconds. As would be expected, the details of the search activity differed greatly from the previous study. Rate and duration of fixation were not meaningful measures here, since the eyes tended to track the sweep line a good deal of the time, making occasional saccadic movements in and out along that line. Figure 8 is typical of the search pattern used by all our subjects in this task. In terms of where the eyes were pointed (fixations not being very appropriate), the spatial



34 AND ABOVE

23 TO 33

12 TO 22

11 AND BELOW

Fig. 7. Spatial distribution of fixations on a 30° circular field of search. Note that this was an "empty field" situation. This type of distribution would not be expected in the searching of a complex visual display.

distribution in this case was quite similar to that found in the earlier study on free search in an empty field.

The lastest work has dealt with the problem of how search activity varies as a function of shape and extent of the search field. Various shape-size combinations were used, with the hope that generalizations might be arrived at which could be applied to predict the inherent search behavior in any given situation. The experimental work has been completed, but we have had no opportunity to analyze the data as yet.

In closing, I would like to say that the electrical method of recording ocular activity has proven to be very satisfactory for problems of this kind, and should definitely be considered by anyone planning to do work in this field in the future.

Fig. 8. A typical example of the scanning method employed by subjects during radar monitoring. This represents one rotation of the sweep line – about 8 seconds.

REFERENCES

1. Ford, A. Significance of terminal transients in electro-oculographic recordings. *A.M.A. Arch. Ophthal.*, in Press.
2. Ford, A., and Leonard, J. L. Techniques for recording surface bioelectric direct currents. *USN Electronics Lab. Res. Rep.* 1958, No. 839.
3. Ford, A., White, C. T., and Lichtenstein, M. Analysis of eye-movements during free search. *J. Opt. Soc. Amer.*, 1959, **49**, 287.

THE TELEVISION EYE MARKER ON A CHANGING VISUAL WORLD

N. H. MACKWORTH, E. LLEWELLYN-THOMAS and S. HOLMQVIST

Introduction

There are a number of problems in many practical and industrial situations which, for solution, require the marking of the line of sight of the human operator on to the visual world surrounding him. This was expressed long ago by Shakespeare, when he specified

> "An eye more bright than theirs, less false in rolling,
> Gilding the object whereupon it gazeth."

Some Earlier Work on Static Displays

The underlying experimental technique which eventually met this requirement was that of Dodge(1) who, more than fifty years ago, used the bright spot in the eye due to the corneal reflection. Many investigators have since used this method to great effect to record where people look when they are considering static pictures. In particular Buswell(2) and Brandt(3) have demonstrated that there is no great problem in photographing the successive positions of the corneal reflection. Subsequent projection of these records back on to the image of the original static picture or text, gives, with a certain amount of patience, the series of positions adopted by the eye fixations in scanning the visual material. Not only are these points in the correct order, but the time intervals between the fixations can also be obtained by special methods, Burrow(4), and subsequently written on the record.

Background to the Present Problem

The challenging problem is to mark the altering point of view on to swiftly moving scenes, in which there are very rapidly altering visual signals; for example in a large action information centre, or in the landing of an aircraft. Another example is in the design of the visual presentations to be given to the encapsulated astronaut, straining to extract survival instructions from his inevitably blurred television screen. This last example is especially interesting as Hauty(5) has found that the decrement in vigilance due to prolonged isolation can be avoided by good equipment design in such displays.

Another urgent set of problems centers around the analysis of the visual seeking responses noted during human watchkeeping — especially those found in radar monitoring. Holland(6) has brilliantly demonstrated the need for a clearer understanding of the behavioral reasons for the marked decline in the probability of detection of visual signals during watchkeeping spells of an hour or two Mackworth(7). In fact, more must be discovered about the searching, seeking, facilitating and readying responses that are an essential preliminary for making an observation successfully.

Spatial Factors in Searching

The spatial analysis of visual searching is clearly of great importance here in determining why spatial trends and tendencies assist and hinder detection in visual vigilance, Nicely and Miller(8), Baker(9). This could be in terms of the average incidence of fixations on particular areas of a static display, as in the recent interesting work done by Ohio State investigators, Enoch and Fry, in their unpublished studies of aerial photographs. (Such analyses might well be extended to radiologists and their methods of search of X-Ray films.)

Temporal Factors in Searching

In changing displays the spacing of the wanted signals in time is also of great importance. For some years now it has been clear that temporal expectancy had a definite influence on the likelihood that a faint and fleeting signal would be reported at all during a long watchkeeping period, for example, when the spacing of these events in time was very irregular, Mackworth(7), Deese(10). But it was only very recently that Baker(11) demonstrated that removing this irregularity in the temporal pattern was one of the most important single changes one could produce in a display to avoid a decrement in the percentage of detections as the watch proceeded. This was done quite simply by spacing out the same wanted events at equal and fixed time intervals, and no decline in efficiency was then obtained, at least with the limited spatial searching involved in a simulated radar task.

Another most valuable contribution on the temporal factors has come from Holland(6). He demonstrated that the temporal pattern of the signals detected in human monitoring determined the rate at which signal-seeking responses were made, in this case to the experimental display which was a dial which could be read only when the subject illuminated it by depressing a light-switch.

Important practical consequences of this study are that the environment has such a marked effect on the individual's signal-seeking behavior, emphasizing that complex man-machine monitoring systems ought to be able to sustain the human monitor in his task of sounding the alarm, Hickey and Blair(12). This may be a military matter, as in reporting the start of a missile attack, or an industrial problem, as in detecting a runaway atomic energy unit.

Far-reaching consequences of Holland's work also lie in its implications for linking together the basic sciences of animal and human behavior. For example, the results can be taken as evidence that detecting a signal in a vigilance task reinforces subsequent looking behavior. This fits in well with the results from many previous studies on animal behavior. Exciting parallels can be noted between the results on the rate at which signal-seeking responses are made during long watchkeeping spells, and the rate at which food-seeking responses are made by animals such as pigeons, Skinner(13).

Spatial and Temporal Factors Analysed Together: The Essential Need

Scientific precision certainly demands many studies of the effects of temporal patterns of events as such, without any spatial searching, in prolonged monitoring.

But practical needs demand that spatial uncertainty is also brought into the experimental settings, as in the recent studies by Baker(11) with a simulated radar display.

An interesting approach is that of Blair(15). He mounted a headlight on his subjects, and their watch-keeping was undertaken in a dark room. They had to illuminate the dial with their head-light in order to read the pointer, and thus information on signal-seeking movements due to the head and eyes was obtained. Abnormal readings of the pointer were given at regular one-minute intervals, and automatic records of the arrival of the light on the dial were made. These confirmed Holland's findings, mentioned above, in some subjects only; these were the people who turned the seeking light away from the dial just after a signal occurred, and brought it back again as the next signal was due. Other subjects kept the light on the display in a fairly continuous manner.

Although this simple method was used with one dial only, much further information could probably be obtained if several dials were searched in this way. Again abnormal readings could be given at regular intervals, but these unusual readings could come at random from different dials for a time, and then tend to come from one dial in particular. (See also Jerison and Wallis(16)).

Indeed, really effective signal-seeking behavior must often depend not only on the person expecting a signal at a particular moment, but also on his expecting that signal from a particular place. It is not enough to be on the *qui vive* without knowing *où* as well — unless one is a pigeon is a small box. For human behavior there is often a critical point in space, just as much as there is a critical stage in time. With the highly symbolic and detailed displays of modern technology, the operator must have his line of sight within a degree or two of the currently important area in his field of view, Williams(14). The visual input is achieved by a remarkable selection of the data available by shifting the gaze, and looking at the wrong place at the right moment is of no value. This is especially true when the signal is brief and fleeting. Much more needs to be done on monitoring tasks in which the signals appear on any one of several displays widely separated in space. Decrements with prolonged work do not appear to be so readily demonstrable as with single source displays, Jerison and Wallis(14).

The problem is as much civilian as military. Thus an automatic production line may pace the industrial inspector to the extent that his gaze must be in place at the right instant to select and reject a faulty product, as he will have no second look, Colquhoun(17, 18). Another example, closer to all of us, is the most common and dangerous of the man-machine relationships, the automobile and its driver. To be looking in the right place at the right time becomes a matter of life, or, too frequently, death.

Some Existing Methods and Techniques for Running Records of Visual Search

Much can be done by direct observation, as in the airborne studies of navigator duties by Christensen(19). He wrote down a description of the actions

taken by navigators and radar operators, during a series of arctic flights. Similarly, the experimenter, watching the controller in an action information center, can tape record a description of the particular display being selected for consideration at the moment. These methods are most useful for a quick analysis. But to achieve an adequate sampling which would be faster than about one observation every five seconds, it is usually necessary to use some other aid, such as a stenotype machine. Alternatively, a movie can be taken of the behavior during visual monitoring, as in recent unpublished research by Baker. Although this method is most useful, and gives great precision in time, it is not very accurate in the spatial recording of the shifting gaze.

Required New Technique

The basic need then, is to record continuously the altering position of the line of sight, in relation to the moving and changing visual world. This would enable a serial analysis of behavior to be undertaken, especially to see to what extent the direction of the gaze is a function of head movements, and to what extent a function of eye movements. If a detailed analysis of the spatial selection of the visual cues being chosen at a particular moment, is to be attempted, then precision of the order of plus or minus one degree in the recording of the line of sight is desirable. Wendt(20) foresaw the need for this kind of technique, in superimposing a fixation dot on a motion picture scene.

The Laboratory Method — A First Attempt at the Television Eye-Marker Technique

A method has been devised which records the signal seeking responses of the eyes only. In this laboratory procedure the head must be fixed to a heavy bench by a biting clamp. This prevents any head movements at all. Two television cameras are used; one of these views the operator's visual world, the other takes a close-up picture of one of his eyes. This gives an image of the corneal reflection, termed the Eye Marker, which appears as a small spot of light moving about in a blank frame. The scene and the eye marker pictures are superimposed electronically. The resultant combined picture can then be viewed directly on the television monitor, and also photographed by a movie camera for subsequent analysis.

The most useful general arrangement is shown graphically in Fig. 1. This laboratory method was demonstrated at the meeting by a motion picture. It is described in some detail elsewhere, Mackworth and Mackworth(21). One interesting application of this, is the study of why people can look directly at a target for which they are searching, without being aware that they have found it — the small-boy-looking-for-his-cap syndrome. They are not aware in the sense that, although they may visibly pause while fixating on the target, they do not report its presence by pointing to it manually as well.

The Head Mounted Camera — A Second Attempt at TV Eye-Marking — Still in Progress

Obviously there are great advantages in a similar system which, during visual search, permits head movements as well as eye movements. Work is now in prog-

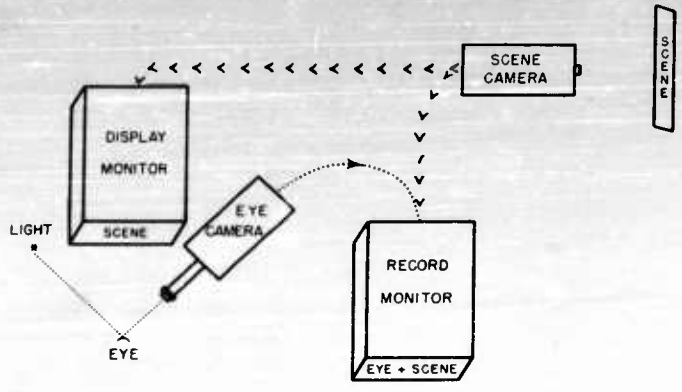


Fig. 1.

ress to do this with one television camera mounted on a helmet worn by the subject. Head movements are recorded as the changing scene moving across the recording monitor screen. Thus, for example, when the subject turns his head, the visual world streams across the screen, as if a movie camera had been panned round. Eye movements are expressed as before, by a spot of light from the corneal reflection, and this marks the fixation point within the area of the visual world selected by these head movements.

The arrangement now being tested consists of an RCA Industrial TV Camera, mounted on a modified helmet. A beamsplitting prism is mounted directly in front of the camera lens, and on to one face of the beam-splitter, a modified image of the eye is projected. The scene passes through the beam-splitter from the other face. The TV camera tube thus sees an optically mixed image, consisting of the scene with the image of the eye superimposed.

As the only portion of the eye which is illuminated brightly, is the eye spot, the composite picture appears as the scene, plus a spot of light, showing the position of eye fixation at that instant.

The eye is illuminated by a small bulb held against the side of the nose, near the non-dominant eye. The eye does not appreciate this light to any extent. It is reflected from the surface of the eyeball, and transferred by a lens and prism system to the face of the beam splitter. By adjustment of the magnification of the eye image, the position of the spot of light displayed on the composite scene coincides with the position of eye fixation at that instant.

It is a pleasure to have the opportunity of acknowledging that three years ago Dr. F. W. Campbell of the Department of Physiology, University of Cambridge, put forward the general idea of mounting such recording equipment on the head. Dr. W. H. Johnson of the Defence Research Medical Laboratories in Toronto suggested the division of the standard industrial TV camera into two parts.

Then again, much help has been received on the technical side, especially from G. G. Reicheneder and Mr. C. J. Deane — as well as from many others such as Mr. L. E. Cullum, Mr. R. Howat, Mr. S. H. Macdonald, Mr. J. H. Royce, Mr. R. G. Olsson and Mr. A. Davidson.

REFERENCES

1. Dodge, R. An experimental study of visual fixation. *Psychol. Monogr.*, 1907, **8**, No. 35.
2. Buswell, G. T. *How people look at pictures.* Chicago: Univer. Chicago Press, 1935.
3. Brandt, H. F. *The psychology of seeing.* New York: Philosophical Library, 1945.
4. Burrow, T. *Science and man's behavior.* New York: Philosophical Library, 1953.
5. Hauty, G. T. Psychological problems of space flight. Paper to Second International Symposium on the Physics and Medicine of the Atmosphere and Space. San Antonio, Texas, Nov. 1958.
6. Holland, J. G. Human vigilance. *Science*, 1958, **128**, 61-67.
7. Mackworth, N. H. *Researches on the measurement of human performance.* Medical Research Council's Special Report Series No. 268. London: Her Majesty's Stationery Office, 1950.
8. Nicely, P. E., and Miller, G. A. Some effects of unequal spatial distribution on the detectability of radar targets. *J. exp. Psychol.*, 1957, **53**, 195-198.
9. Baker, C. H. Attention to visual displays during a vigilance task, I. Biasing attention. *Brit. J. Psychol.*, 1958, **49**, 279-288.
10. Deese, J. Some problems on the theory of vigilance. *Psychol. Rev.*, 1955, **62**, 359-368.
11. Baker, C. H. Attention to visual displays during a vigilance task, II. Maintaining the level of vigilance. *Brit. J. Psychol.*, Feb. 1959.
12. Hickey, A. E., and Blair, W. C. Man as a Monitor. *Human Factors*, 1958, **1**, 8-15.
13. Skinner, B. F. The experimental analysis of behavior. *Amer. Scientist*, 1957, **45**, 343-371.
14. Williams, S. B. Visibility on cathode ray tubes; Viewing Angle. *J. Opt. Soc. Amer.*, 1949, **39**, 782-785.
15. Blair, W. C. Measurement of observing responses in human monitoring. *Science*, 1958, **128**, 255-256.
16. Jerison, H. J., and Wallis, R. A. Experiments on Vigilance: One clock and three clock monitoring. Second in a series. Unpublished. ASTIA Doc. No. AD118171. *USAF WADC tech. Rep.*, 1957, No. 57-206.
17. Colquhoun, W. P. Vigilance and the inspection problem. *Nature*, 1957, **180**, 1331-1332.
18. Colquhoun, W. P. The effect of a short rest pause on inspection efficiency. Unpublished Medical Research Council Applied Psychology Research Unit Memorandum. Feb. 1959.
19. Christensen, J. M. Aerial analysis of navigator duties with special reference to equipment design and workplace layout. II. Navigator and radar operator activities during three arctic missions. Unpublished. *USAF Memo Rep.*, 1947, No. MC REXD — 694 — 15 A.
20. Wendt, P. R. Development of an eye-camera for use with motion pictures. *Psychol. Monogr.* 1952, **66**, No. 7.
21. Mackworth, J. F., and Mackworth, N. H. Eye fixations recorded on changing visual scenes by the television eye marker. *J. Opt. Soc. Amer.*, 1958, **48**, 439-445.

DISCUSSION

M. D. ARNOULT: Some years ago, a group of us who were working on problems of form perception attempted to distinguish different kinds of perception in terms of the "task" presented to the subject. In this way we hoped to standardize our terminology to an extent not common in the general literature. We agreed to distinguish three main classes of "tasks":

(1) *Discrimination* — "tasks" in which the subject can respond by indicating "Same" or "Different"; *detection* and *localization* are special cases of this kind of "task".

(2) *Recognition* — "tasks" in which the subject responds by saying, "That one is the one I saw earlier." *Matching* and *reproduction* are probably special cases of this kind of "task."

(3) *Identification* — "tasks" in which the subject responds by saying, "That is an X."

In addition, of course, there are the kinds of performance measures which we call *physiological*, in which the subject plays a somewhat more passive role than in the cases cited above.

It is clear from the papers presented here this morning that research is proceeding vigorously along all of these lines. Some investigators are using essentially physiological measures, such as eye movements, while others are using tasks involving discrimination, recognition, identification, or combinations of several of these. What distinguishes these papers from the ones that will be presented this afternoon is that they are, or should be, starting points for making inferences about the kinds of control mechanisms that orient the eye with respect to the target, and the kinds of gating mechanisms that determine whether the target will elicit a differential response. Insofar as I would criticize this morning's papers at all, it would be on this point. In order to develop an adequate set of principles relevant to visual search techniques, we need to know what neural control centers respond to what kinds of inputs; we need to know what are the mechanical properties of the muscle systems involved; we need to know what patterns of facilitation and inhibition occur, and what the threshold values are for all the responses we can detect. Most of the hypotheses we investigate with regard to these problems will originate as inferences from overt behavior, so we must relate our measures to the formal properties of the stimuli we use and to events in the history of the observer.

These considerations lead me to be dissatisfied, for example, with the experiment reported by Mr. White to the extent that it was concerned only with the fixations of the eye and not with the intervening movements. For a discussant I am now going to do something inexcusable and talk about my own research. This was a study, in which observation of the characteristics of eye movements themselves led to a number of inferences which are relevant, I think, to the research reported today. I recorded eye movements by a method that is infrequently used.

I required the subject to move his eyes between targets which were in predetermined positions about 20 or 30 degrees apart and took a still photograph of each movement separately. I discovered that most of the movements were along curved rather than linear paths. The likelihood of curvature, the direction of curvature, and the amount of curvature seemed to depend upon the direction of movement. Horizontal movements were curved about 40 per cent of the time and almost always in the upward direction. Vertical movements were curved about 72 per cent of the time and usually in the nasal direction. Diagonal movements were curved 80 per cent of the time and in various ways — upward, downward, mixed curve and straight line, double curvature, and so on. In the most extreme case observed, the point of maximum curvature was 8° of visual arc from what would have been a straight line path to the target.

Having satisfied myself that these results were not artifacts of the method of measurement, I asked the question, "What type of controlling mechanism could allow such variation in the route taken by the eye and, at the same time, insure the arrival of the eye at the proper fixation point?" Three hypotheses seemed worthy of consideration.

The first hypothesis, which was originally proposed by Stratton in 1906, is that both the deviation and its subsequent correction are the result of learning. Stratton suggested that the association of attention with convergence would lead to a tendency toward convergence movements whenever a target was being attended to. There are several objections to this hypothesis: first, not all the movements are of the convergence type; second, the variability in the amount and direction of curvature would require that the eye be continuously receiving information about its momentary position. At the same time, the hypothesis should not be summarily dismissed, and I would like to see someone like Dr. Henneman explore systematically the experiential factors that may be correlated with variation in eye movements.

The objections to the first hypothesis could be overcome by supposing that the eye is under continuous feedback control, such that the deviation of the eye from a straight line path is itself a cue for the correction that insures arrival at the target. The difficulty with this second hypothesis is that the total time involved seems too short for such a feedback loop to be established. Furthermore, the substance of recent eye-movement research (for example, the work of Lion and Brockhurst at M.I.T.) indicates that an eye movement is a unitary event, unmodifiable once it has been initiated. Some of the corrections introduced in mid-movement are so extreme, though, that it is difficult to imagine any other basis for their occurrence, so I would like to see the feedback hypothesis investigated further. The apparatus described by Mr. White would be ideal, if used in conjunction with photographic recording. Having complete control over time relationships in the sequence of events involved in a movement would allow the introduction of a change in the location of the target at various times just before and just after the movement was initiated. If the movement can be corrected in correspondence with a change in target location, then the feedback hypothesis would be greatly strengthened. We might also ask the question, "To

what extent is control maintained through visual feedback and to what extent through kinesthetic feedback?" The apparatus used by Dr. Cohen seems to me to be highly appropriate for investigating such a problem. A determination of the exact paths of eye movements under "blank-out" and no "blank-out" conditions would be an excellent extension of the work on kinesthetic cues performed by Dr. Ludvigh some years ago.

The third hypothesis which might account for the observed curvature is one which implies that the direction and amount of curvature are essentially unpredictable. In moving the eye from any given point "X" to any other given point"Y," it is necessary for each of the extraocular muscles to perform a specific amount of work. It is not necessary, however, for that work to be distributed any particular way in time. It is possible, for example, that one of the muscles might be an "early starter" and perform most of its total work during, say, the first third of the total movement time; another muscle might be a "late-starter," exerting most of its influence during the later stages of the movement; and still another might have its work fairly uniformly distributed throughout the time that the eye is moving. The likelihood of a curved movement, and the complexity of the curvature, would then be a function of the extent to which the temporal patterns of muscular activity were mismatched.

This hypothesis leads to two kinds of experiments. First, since the eye must in some sense "know" where it is going before it starts, it becomes very important to obtain the kind of detection data that Smith and Louttit have reported here today. Further, it is necessary to infer from the detection data and its relation to target microstructure the way in which information is transmitted from the visual cortex to the control center for eye movement and how it is translated into the parameters which will determine the movement. The second kind of experiment that this hypothesis could inspire would be one in which recordings were made simultaneously from the differ e extraocular muscles in order to find out whether the hypothesized temporal mismatching does, in fact, occur, and whether the distributions of muscle activity in time can be related to the path actually followed by the eye.

My purpose in discussing these eye-movement data at some length has been to use them as an illustration for the two main points that I would like to make. The first point is that, when you are concerned with a problem such as the "Basic Eye Characteristics Related To Search," it is necessary constantly to look for inferences that can be made about the probable natures of the underlying control systems. The second point is that such inferences are potentially available in the behavioral data from many kinds of tasks, and we should be careful not to make any gratuitous assumptions about the usefulness of "physiological" measures as opposed to "psychological" measures.

In some of the papers we have heard this morning the emphasis was on the development of new kinds of tasks for the observer; in others, the emphasis was on the development of new methods of measurement. In both cases my impression is that the developments are ones which have a high potential for future use. What

I would now like to see is an exchange of tasks and procedures among the individuals concerned. For example, the ingenious eye-movement recording techniques shown us by Dr. Mackworth and Mr. White should be incorporated into experiments on detection, recognition, and identification; these kinds of tasks, in turn, need to be investigated in relation to prolonged homogeneous visual stimulation, with attention to the structural properties of the stimulus and the past experience of the observer. If this meeting increases the probability that this sort of cross-fertilization will occur, then it will have made a significant contribution to the ultimate understanding of the problem of visual search.

H. LEIBOWITZ: Beginning with the keynote talk by Dr. Lamar, and continuing through the subsequent papers presented yesterday and today, the problem of how much time is consumed by a single visual "look" has continually been mentioned. Historically, the time so consumed has been referred to as the "fixational pause of the eyes" by Cobb and Moss, who provide a summary of earlier studies(1). It has become clear from the previous papers presented to this symposium, that the temporal characteristics of the fixational pause are important both from the theoretical and practical points of view. In fact, the ultimate success of the application of quantitative models relating to search behavior, such as the one presented by Dr. McGill, may well depend on a precise determination of the time utilized by fixational pauses under different experimental conditions. In this context, the techniques described by White and by Mackworth are particularly appropriate as they provide the methodology necessary for quantitative determinations under a wide variety of conditions of observation. That it will be necessary to investigate the temporal characteristics of eye movements in general, and the fixational pause in particular under *different* conditions of observation is suggested by the discrepant results obtained by different investigators. Cobb and Moss report a normal distribution of pause durations with a range from .071 to 0.25 second and a mean of 0.15 second(1). Leibowitz and Bourne, for a different visual task, report a skewed distribution with a mean of 0.48 and a mode of about 0.30 second(2). White has presented data with a mean of approximately 0.33 second and a range from 0.25 to 0.50 second. It would be expected that ultimately one could account for these differences by showing that they represent special cases of more fundamental fixational pause relationships.

The Henneman paper is a striking example of the way in which various research areas in psychology can and do overlap. I am thinking in particular of the current research efforts by psychologists which are classified under the heading of concept formation. For a representative paper, see Archer, Bourne, and Brown(3). These studies are concerned with the effects of relevant and irrelevant information on concept formation. Henneman is concerned with ambiguous stimulus data, but the experiments are similar in design and execution. The concept formation studies vary sensory characteristics but deemphasize their importance as purely sensory variables. Henneman, however, is specifically concerned with the role played by systematically varied sensory characteristics. When two types of investigations overlap each other to such a great extent, it provides additional proof of the essential continuity and interdependence of many terms used by psychol-

ogists such as irrelevant cues and stimulus ambiguity, transposition, stimulus generalization, perceptual constancy, etc.

The paper by Cohen illustrates the rather infrequent case in which a phenomenon, previously studied for theoretical reasons, can be shown to be relevant to an important applied problem. The *Ganzfeld* studies have been known and discussed for years(4, 5), but this is probably the first time their relation to a visual problem has been made explicit. One question can be raised concerning the generality of these results as the homogeneity of stimulation encountered in visual search may not be as uniform as in the experimental *Ganzfeld*. Therefore, the extent to which these data are of practical relevance will be limited by the similarity of stimulus conditions. This is not meant to distract from the value of this paper, because it does provide a description of the *maximum* deleterious effects of homogeneous stimulation and as such furnishes a valuable base line for further analysis.

REFERENCES

1. Cobb, P. W., and Moss, F. K. The fixational pause of the eyes. *J. exp. Psychol.*, 1926, **9**, 359-367.
2. Leibowitz, H., and Bourne, L. Time and intensity as determiners of perceived shape. *J. exp. Psychol.*, 1956, **51**, 277-281.
3. Archer, E. J., Bourne, L. E., and Brown, F. G. Concept identification as a function of irrelevant information and instructions. *J. exp. Psychol.*, 1955, **49**, 153-164.
4. Metzger, W. Optische Untersuchungen am Ganzfeld II. Zur phänomenologie des homogenen Ganzfelds. *Psychol. Forsch.*, 1930, **13**, 6-29.
5. Koffka, K. Principles of gestalt psychology. New York: Harcourt Brace, 1935.

TOWARD A THEORY OF VIGILANCE*

C. H. BAKER

Little is known concerning the stability of perceptual performance as a function of time. One area which has excited considerable interest in recent years, however, concerns changes in perceptual performance in time under conditions where weak and randomly occurring signals, serially presented, must be observed and responded to. The best known, and among the earliest experiments in this field have been reported by Mackworth(18, 19, 20, 21, 22).

Mackworth devised a Clock Test having a single rotating hand on a plain dial. Once each second the hand jumped forward 3.6 degrees to a new position, 100 jumps completing a revolution. Occasionally, however, the hand jumped double the usual distance and subjects responded to these double jumps, or "signals," by pressing a button. The interesting feature of these studies was that, as time progressed, fewer and fewer signals were detected. Typical data(22) showed that in four successive half-hour periods, the percentages of signals escaping detection were, respectively, 16, 26, 27, and 28. Such a decrement in performance in time has been demonstrated by more than 25 investigators working independently, of whom references 1, 3, 16, 17, and 25 may be considered representative. The decrement has been shown to occur in the absence of any change in the sensory threshold(15, 25, 26) and is thus considered to be central in origin.

Theory

In a study of the effect of signal frequency, Jenkins(16) found that "the probability that an observer will detect a particular signal depends much more upon the prevailing or mean signal rate than upon the length of time that has elapsed since the preceding signal was detected." In examining these two possibilities Deese(12) advanced an expectancy hypothesis to account for the general level of performance during a vigilance task. It states that "the probability of detection — is determined by a large and rather indeterminant number of signals preceding the signal in question — the observer — continuously performing a kind of averaging of previous input in order to extrapolate the results to future behavior of the search field," and so, "expectancy should be low immediately after a signal, should increase as the mean intersignal interval is approached, and finally should become quite high as the intersignal interval grows beyond the mean."

This hypothesis implies that the observer would be 'eternally hanging on an expectant limb' after a series of signals terminated, and consequently has been expanded(6) to read, "as the interval grows still longer expectancy again falls to a low level." It should be noted that the term 'expectancy,' as used in this paper, does not necessarily imply any conscious formulations on the part of the observer. The degree to which he is aware of such expectancies is unknown.

The work of Mowrer(23) serves admirably to illustrate the expended hypothesis. In order to, "obtain an objective record of the course of expectancy," he used

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a simple reaction time technique, subjects responding to a tone which appeared, "at an unvarying interval of 12 seconds." Occasional "test trials" were inserted, these consisting of intervals of as small as three to as large as 24 seconds. "As the test interval approached the standard interval the reaction time became progressively shorter (with rising expectancy) until, at the 12 second test interval — which was, of course, the same as the standard interval — the obtained reaction time was "normal". . . . As the test intervals varied beyond 12 seconds, up to 24 seconds, the average reaction time again increased but not to the same heights it had reached on the shorter test trials. . . (23)."

Mowrer's study has been repeated(4) using series of 20 unvarying intervals of 10 seconds, followed by a 21st "unexpected" interval of 2, 5, 20, 25, and 30 seconds, on separate trials.

In Fig. 1 the data from this study are plotted in terms of the percentage increase in time to respond to a 21st signal inserted after the five "unexpected" intervals. In the case of signals at 202 and 205 seconds the mean response time was longer (43 and 37 per cent respectively) than the mean of the preceding series. This difference is significant at the one per cent level, although the apparent downward trend of the three "late" signals is not.

Figure 1 is interpreted as the general shape of the expectancy function — expectancy drops to a low level shortly after each signal, mounts rapidly as the next signal is expected, and then tends to taper off if the expectancy is not confirmed. Experiments employing regular intervals of two minutes, followed by "unexpected" intervals, have yielded similar results.

Results

In addition to explaining the decrement in performance often found in vigilance tasks, a satisfactory model must also explain the effects of at least six factors which are known to retard or accelerate the decrement. These factors are given below, followed in each case by a brief description of how the position outlined above can account for their known effects.

Rate of Signal Appearance. A greater percentage of signals is detected, or signals are responded to more quickly, as signal frequency increases(8, 10, 11, 16, 24).

This follows for two reasons: (a) observers have a larger sample of data upon which to base expectancies, and (b) it has been shown(28) that observers can estimate short intervals with greater precision than longer intervals. It should be noted that we are not concerned here with the oft-found decrement in performance, but with the overall level, i.e., with the proportion of signals detected during a complete session.

Inter-signal Interval. The more regular the temporal interval between signals, the more signal detections(4, 6).

Here we are concerned with the decrement in detection performance in time. The accuracy of perception of the temporal structure of a series of signals must be a function of the degree of regularity of the series, and the more accurate the

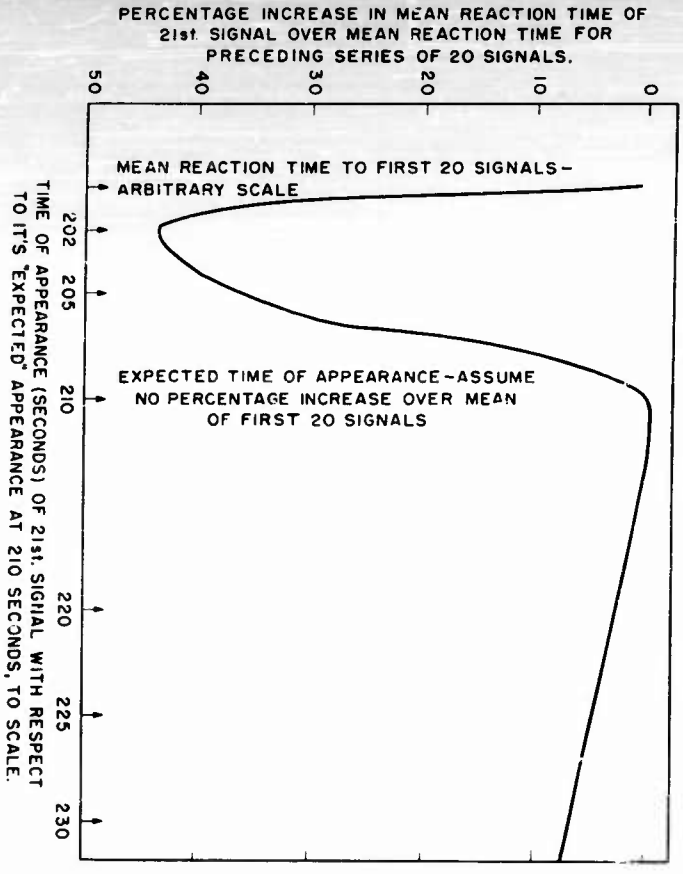

Fig. 1. Showing the Mean Percentage Increase in Reaction Time to a 21st Signal Appearing at Shorter and Longer Intervals than that employed in the Preceding Regular Series of 20 Signals, N = 12.

perception the more probable the confirmation of expectancy. For the case of signals occurring with less apparent regularity, confirmation of expectancy is less probable. Lack of confirmation lowers the apparent signal frequency, with the consequent lowering of the overall level of performance. This lowering of the overall level of performance proceeds in successive steps in time. These steps are invariably masked when the results from individual subjects are pooled, and appear as a smooth decrement.

At some point in time the observer abandons his efforts to build expectancies. This occurs when the apparent frequency is so low that the intervals are too long

to permit extrapolation with any precision. The probability of signal detection is now determined solely by chance events, i.e., he is looking at the right place at the right time. Such chance events, being independent, result in a consistent probability of detection as time progresses, i.e., in performance which shows no further decrement, as typified, for example, in Mackworth's studies(22).

The above explanations of the effects of signal frequency and interval regularity are basic to the expectancy position. Expectancy is a function of signal frequency and interval regularity. It follows that any condition which reduces either frequency or regularity, or both, will result in a lower overall level of performance, or a greater decrement in time, or both.

Signal Magnitude. Signals of large magnitude (size, duration, intensity) escape detection less frequently than those of smaller magnitude(1, 1).

Such signals make confirmation of expectancy more probable, simply because the greater the magnitude the greater the probability of perception.

Knowledge of Results. Knowledge of results during a vigilance session prevents a decrement in performance from occurring(22).

Explanation of this effect is based upon the proposition that knowledge of results serves to establish perception of the true sequential nature of the series and so to increase the probability of expectancy confirmation, i.e., knowledge of results, in this particular context, is synonymous with feedback. In other words, telling an observer, "yes, that was right," or, "you missed one there," tells him, in effect, that there is a signal *now*, and nothing more. We would not, therefore, expect knowledge of results to be a potent factor until the task had proceeded for some time, and, indeed, Mackworth found "a clear advantage in favor of the men who were supplied with knowledge of results, except during the first half-hour"(22).

The proposition that knowledge of results in a vigilance situation serves simply as feedback by revealing the true temporal nature of the series has recently been tested(4). Three experimental conditions were compared. In one, the "no information" condition, no information was given when a signal was detected or missed. In the second, knowledge of results was given: a small display was illuminated for one second above the main display, to read "correct," "missed," or "false," as appropriate. In the third or "feedback" condition a missed signal was repeated a second, a third, or an even greater number of times, at intervals of five seconds until it was responded to, but the observer was credited with a miss even though he eventually responded. The Mackworth intervals mentioned above were employed in this study as they are known to produce a decrement when no information is supplied. Seventy-five paid female subjects were employed, twenty-five being randomly assigned to each condition. (The procedure of testing each subject under each condition was avoided because of the possibility of order effects.)

The data are shown in Fig. 2. The decrement in the "no information" condition is significant at the 0.02 level of confidence. As hypothesized, there is no

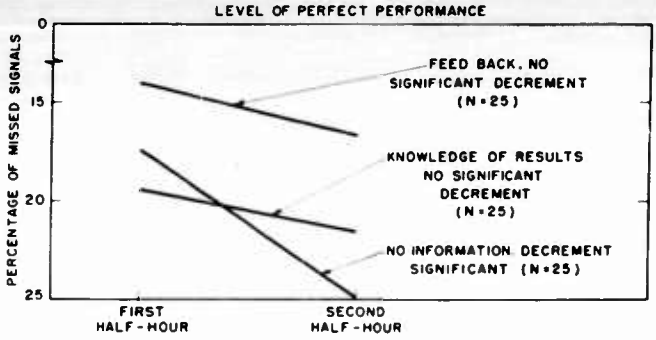

Fig. 2. Showing the Percentage of Signals Missed under Each of Three Experimental Conditions during the First and Second Half-Hour Periods.

significant decrement in the "knowledge" or "feedback" conditions. The general superiority of the "feedback" group is attributed to chance differences between the groups.

Environmental Factors. Significantly more signals are detected at 79°F than at 70° or 90° when subjects are dressed in "shorts"(20, 22). High ambient noise levels also impair performance(9).

The explanation of these effects is simply that any distraction which competes for attention with the vigilance task will lower the apparent signal frequency and consequently result in reduced performance.

Knowledge of Signal Location. When signals appear at locations which cannot be predicted, performance is generally poorer than when the location is known, i.e., when visual search is not involved(15). This follows because under the condition of uncertainty of signal location an expectancy may be "correct" but the signal may appear at a location not being scanned at that moment. Such unconfirmed expectancies will serve to lower the apparent signal frequency. Supporting data have been reported(7, 15, 26).

Discussion

An attempt has been made here to examine an expectancy hypothesis of vigilance proposed by Deese(16), expand it, illustrate it, and present some supporting data.

Two merits of the position outlined here are worth emphasizing. First, in vigilance experiments performance never becomes nil, i.e., the curve of performance always becomes asymptotic with the time base and never intersects it. The expectancy position can account for this phenomenon. Second, it has been shown that knowledge of results can assume new meaning. Knowledge of results is typ-

ically (and vaguely) considered as a motivating factor — something akin to the use of incentives (the individual approach), or to the use of authority or peer figures (the social approach), in inducing high and sustained levels of performance. But the mode of operation of such knowledge in a vigilance task has been shown to differ fundamentally from this general concept: here "knowledge of results" provides nothing more than knowledge of the true nature of the temporal structure of a series in order that observers can make accurate temporal extrapolations.

This approach has avoided what is an obvious and possibly a most important factor in determining the efficiency of perceptual performance in time, i.e., motivation. Fraser has shown(14), for instance, that performance is superior on a vigilance task if the experimenter sits quietly behind the observer, rather than outside the room, presumably because the experimenter is an authority figure in this particular situation. Worth mentioning, too, is our understanding that at sea, officers of the watch make many more sightings than do members of the watch. (In passing we can note the findings(2, 20, 25) that there is no relation between intellectual ability and performance on a vigilance task.) Data, however, are few.

The theoretical position outlined above, however, should be true at any level of motivation on the part of the observer and even in the case of a changing level of motivation. The performance of even the most highly motivated observer must in time decline if the situation is such as to produce a decrement — small, brief, infrequent signals, irregularly spaced, with no feedback concerning performance. On the other hand the least motivated subject could turn in an acceptable performance if signals were large, prolonged, frequent, fairly regularly spaced in time, with feedback proved.

In closing it was worth pointing out that in the experiments described here the measure of performance has been the percentage of signals escaping detection. Many other measures have been reported. Considerable emphasis has been placed upon the "effective threshold" technique, which consists basically of increasing signal magnitude in steps until it is reported, i.e., apparent signal frequency and input frequency are the same(13). In view of the data reported above concerning the effects of feedback it appears that use of the "effective threshold" technique will generate data which are not descriptive of the actual situation.

REFERENCES

1. Adams, J. A. Vigilance in the detection of low-intensity visual stimuli. *J. exp. Psychol.*, 1956, **52**, 204-208.
2. Bakan, P. Personal communication.
3. Bakan, P. Discrimination decrement as a function of time in a prolonged vigil. *J. exp. Psychol.*, 1955, **50**, 387-390.
4. Baker, C. H. Three minor studies of vigilance. Defence Research Board of Canada. DRML Report No. 234-2, 1958.
5. Baker, C. H. Attention to visual displays during a vigilance task. I. Biasing attention. *Brit. J. Psychol.*, 1958, **49**, 279-288.

6. Baker, C. H. Attention to visual displays during a vigilance task. II. Maintaining the level of vigilance. *Brit. J. Psychol.*, in press.

7. Baker, C. H., and Boyes, G. E. Increasing probability of target detection with a mirror-image display. *J. appl. Psychol.*, in press.

8. Bowen, H. M., and Woodhead, M. M. Vigilance. The effect of frequency of signals. Med. Res. Council, A.P.U. Memo. Rep., 1956.

9. Broadbent, D. E. The twenty dials and twenty lights test under noise conditions. Med. Res. Council, A.P.U. 160/51, 1951.

10. Browne, R. C. The day and night performance of teleprint switchboard operators. *J. occup. Psychol.*, 1949, **23**, 121-125.

11. Deese, J., and Ormond, E. Studies of detectability during continuous visual search. *USAF, WADC tech. Rep.* 1953, No. 53-8.

12. Deese, J. Some problems in the theory of vigilance. *Psychol. Rev.*, 1955, **62**, 359-368.

13. Elliott, E. Auditory vigilance tasks. *The Advancement of Science*, 1957, **53**, 393-399.

14. Fraser, D. C. The relation of an environmental variable to performance in a prolonged visual task. *Quart. J. exp. Psychol.*, 1953, **5**, 31-32.

15. Garvey, W. D., and Henson, J. B. Effect of length of observing time on earth satellite visibility. *USN Res. Lab. Rep.*, 1958, No. 5094.

16. Jenkins, H. M. Performance on a visual monitoring task as a function of the rate at which signals occur. *MIT Lincoln Lab. tech. Rep.*, 1953, No. 47.

17. Jerison, H. J. Performance on a simple vigilance task in noise and quiet. *J. Acoust. Soc. Amer.*, 1957, **29**, 1163-1165.

18. Mackworth, N. H. Notes on the clock test — A new approach to the study of prolonged visual perception to find the optimum length of watch for radar operators. Med. Res. Council, A.P.U. 1, 1944.

19. Mackworth, N. H. Faulty perception caused by blank spells without signals during experiments on prolonged visual search. Med. Res. Council, A.P.U. 17/45, F.P.R.C. 586(a), 1945.

20. Mackworth, N. H. Effects of heat and high humidity on prolonged visual search as measured by the clock test. Med. Res. Council, A.P.U. 33/46, F.P.R.C. 586(c), 1946.

21. Mackworth, N. H. The breakdown of vigilance during prolonged visual search. *Quart. J. exp. Psychol.*, 1948, **1**, 6-21.

22. Mackworth, N. H. Researches on the measurement of human performance. Med. Res. Council Special Report Series No. 268. London: H. M. Stationery Office, 1950.

23. Mowrer, O. H. Preparatory set (expectancy) — Some methods of measurement. *Psychol. Monogr.* 1940, **52**, No. 2 (Whole No. 233).

24. Pollock, I., and Knaff, P. R. Effect of rate of target presentation on target detection probability. *Amer. Psychol.*, 1958, **13**, 414. (Abstract)

25. Solandt, D. Y., and Partridge, R. C. Research on auditory problems presented by naval operations. *J. Cdn. Med. Services*, 1946, **3**, 323-329.

26. Wallis, D. Auditory and visual search problems. Memorandum Report, Dept. of the Senior Psychologist, Admiralty, 1957.

27. Wilkinson, R. T. Recent research on the effects of lack of sleep. Med. Res. Council, R.N.P.R.C., OES 269, 1955.

28. Woodrow, H. Time perception. In S. S. Stevens, (Ed.), *Handbook of experimental psychology*. New York: Wiley, 1951. Pp. 1224-1236.

VISUAL SEARCH IN UNSTRUCTURED FIELDS*

EZRA S. KRENDEL and JEROME WODINSKY

Introduction

Purpose

The objective of this work was to determine the time required to detect small visual targets in a broad unstructured visual field.

Search was conducted with unaided binocular vision under a range of conditions which included different search areas, contrasts, background luminances, and target sizes of possible significance in field operations. The targets remained constant in position and in time until detected. The single glimpse detection probabilities were small in magnitude and remained constant insofar as these probabilities were controlled by the experimenter. The low single glimpse probability, lack of *a priori* target location designation, and the target's time constancy defined detection under search conditions. Jenkins'(3) distinction between a watch and a search based on the duration of the target is pertinent here. Effectively, in a watch the observer is fixed while the environment passes by; in a search the environment is fixed and the observer goes by.

There were three phases to this study. Phase I was conducted at Bryn Mawr with 25 undergraduates as subjects and examined a general model for visual search. Phase II, a slight extension and overlap of this experiment, was conducted with 5 subjects using the Fels Planetarium of the Franklin Institute as the experimental room. Phase III, a detailed parametric study of the search problem using 4 subjects, was conducted in a conventional experimental room at the Franklin Institute Laboratories. This final phase was the most elaborate study and provides the essential content of this report.

Background

The mathematical model for the data was derived from the analogy between the process of searching for a target and the process of destroying a target by a schedule of firing. The concepts of single shot hit probability and lethal area have direct analogs in visual search. This scheme for studying visual detection was first presented by Lamar(4) during World War II.

Consider a constant, single glimpse probability for target detection, p_{sg}. Assume that successive glimpses, i.e., fixations, are independent. Under these conditions it follows that the probability of detecting the target, P_{kg}, after k independent glimpses can be written:

$$P_{kg} = 1 - (1 - p_{sg})^k. \tag{1}$$

This is so, since the probability of *not* detecting the target after k independent trials is $(1 - p_{sg})^k$. Equation (1) may be rewritten as follows:

$$P_{kg} = 1 - e^{k \ln (1 - p_{sg})}. \tag{2}$$

*This research has been sponsored by Operational Applications Laboratory, Air Force Cambridge Research Center, Air Research and Development Command, Bolling Air Force Base, Washington, D.C., and has been reported in AFCRC TR 59-51.

By defining a scan rate, $\frac{1}{T}$, which is the reciprocal of the sum of the eye's fixation time, T_f, and movement time, T_m, Equation (2) can be rewritten to determine detection probability as a function of time to detection.

$$\frac{1}{T}=\frac{1}{T_f+T_m}, \text{ and } \frac{t}{T}=k,$$

then

$$P(t)=1-e^{\frac{t\ln(1-p_{sg})}{T}}=1-e^{-mt}. \tag{3}$$

The constant, m, in the above exponential cumulative probability function, which is a special case of the Poisson distribution, may be approximated. Let the total number of targets which were detectable be N, and the number of targets detected by time, t, be n(t). If false reports are few, as would be the case in free choice detection decisions, N will be approximately equal to the total number of targets detected.

$$P(t)=\frac{n(t)}{N},$$

$$\frac{N-n(t)}{N}=e^{-mt}. \tag{4}$$

Taking the logarithms of Equation (4):

$$\ln[N-n(t)]-\ln N=-mt. \tag{5}$$

Equation (5) is a convenient means for testing this model for independent random visual search with a constant probability of detection for a single glimpse. A plot of $N-n(t)$ on a logarithmic scale versus detection time on a linear scale should result in a straight line with ordinate intercept N and slope of $-m$.

A cumulative detection probability distribution in the form of Equation (3) is mathematically convenient. For this distribution the mean time to detect a target is:

$$\bar{t}=\int_0^\infty mte^{-mt}dt=1/m. \tag{6}$$

As yet no restrictions have been imposed on Equation (3) to distinguish search from detection. The expression for m may be expanded in a power series as follows:

$$m=\frac{\ln(1-p_{sg})}{T}=\frac{1}{T}\left(-p_{sg}-\frac{p_{sg}^2}{2}-\frac{p_{sg}^3}{3}-\frac{p_{sg}^4}{4}-\cdots\right). \tag{7}$$

After imposing the condition that the target can not be obvious immediately if search is to take place, one obtains:

since $$P_{sg}\ll 1,$$

then $$m\simeq\frac{-p_{sg}}{T}. \tag{8}$$

The parameter, m, which is derived from Equation (3) is thus expressible with great simplicity. The single glimpse probability of detection can be calculated from a knowledge of the detection lobe of the observer's eyes, and a definition of the area under search. The detection lobe may be thought of as a surface of revolution generated by rotating isoprobability contours about the line of sight centered on the fovea.

In our preliminary experiments we attempted to validate Equation (3) and its underlying assumptions. Is m a constant? Is search random and independent? If a line, in fact, is not appropriate for Equation (5) there are two non-exclusive explanations. The slope m may be a function of time. Independent eye movement studies and measurements of the single glimpse detection probability would be needed to determine whether p_{sg} or 1/T or both have changed with time in the search.

The alternative explanation is that the observer is searching in an organized manner and making an effort to avoid re-examining searched-over areas. In an ideal search pattern in which no overlap occurs, the cumulative detection probability becomes the following:

$$P_1(t) = \frac{p_{sg}t}{T}. \qquad (9)$$

A plot of Equation (9) on the same scale and on the semi-logarithmic coordinates suggested for Equation (5) would produce a curve concave upward *below* the linear plot for Equation (5). Equation (9) represents the best performance that the observer can achieve in searching for randomly located targets. Thus, $P_1(t)$ becomes unity for $t = T/p_{sg}$; whereas $P(t)$ in Equation (3) becomes unity after an infinitely long search time. It is of interest to observe that Equation (9) may be derived from Equation (1) by expanding according to the binomial theorem, discarding all quadratic and higher terms, and replacing k by t/T.

In the following sections we will attempt first to demonstrate the validity of this simple model for visual search, and then to study the effects of the size of the area searched, contrast, background luminance and target size.

Experimental Program, Phase I

Procedure

Twenty-five naïve Bryn Mawr undergraduates with 20/20 corrected vision served as subjects for one hour apiece in a visual search experiment. The search field was a white, diffusely reflecting screen illuminated uniformly by a series of photoflood lamps such that its brightness was 5 foot lamberts. The screen was 72 in. x 63 in. in size and the subject was seated 10 feet from the screen with her eyes lined up in an approximately central position. The subject's head was not constrained. The search area intercepted an angle of 0.33 steradians at the subject's eyes. The target was a small circular disk of light. The diameter of the target intercepted a plane angle of 13.2 minutes and a solid angle of 1.2×10^{-5} steradians. Contrasts were not measured with sufficient accuracy to be presented here. The

targets were positioned by means of a Goldie projector having a 7-inch focal length and mounted in a specially designed cradle. A uniform predetermined schedule of 48 target locations which were randomly distributed throughout the search field was used for each subject. Not all of the subjects detected the total of 48 targets during the one hour session.

Prior to the test session, the subject was familiarized with the target. The instructions were to search for the target as rapidly as possible. The method of limits with respect to time was used. A warning signal was given, and the subject began her search up to a maximum of five minutes, after which time was called. When the target was allegedly detected, confirmation was requested while the clock was stopped and the subject continued to regard the target's alleged position. Confirmation was given on the basis of a location as to quadrant and the further designation of central or peripheral field location. Since decisions were not forced, the false report problem was reduced. In the absence of confirmation, the search was continued up to the arbitrary time limit. The next target location was then established with the projector without the subject's awareness, the light turned on, and the alerting signal given.

Results of Experiment 1

The time data for this experiment were arranged in a cumulative distribution for five second intervals. Only two targets were projected for the limiting time of five minutes and these two targets, together with data for ten targets whose search durations above three minutes, were discarded since they were a negligible proportion of the total number of trials.

Figure 1 is a plot of 1052 target detections on semi-logarithmic paper. False reports were negligibly few during the experiment. The description of visual

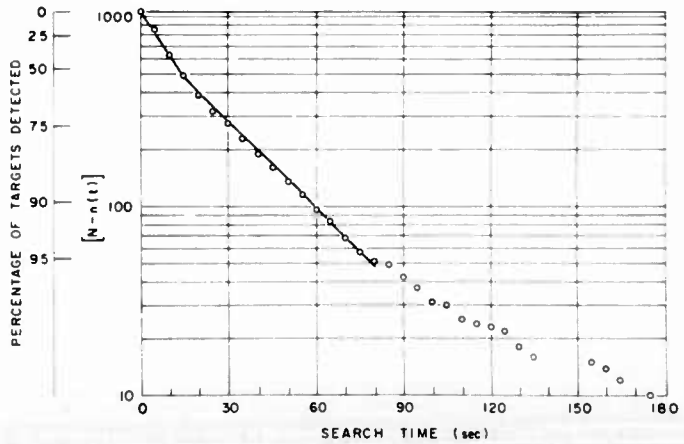

Fig. 1. Percentage of Targets Detected vs. Search Time, N = 1052.

search at the onset of search may lie in a region between the extremes of Equation (5), random search, and Equation (9), search without overlap. Figure 1, which is relatively close to the form of Equation (5) appears to lie in this region. Thus, a structure may exist in the search pattern during early search while the subject can consciously attempt to avoid re-examining previously searched areas. A second possibility for long duration search in that the parameter, m, of the visual search equation changed with duration of search. A previously mentioned reasonable hypothesis is that T will change with search time. It is of interest to note that skilled searchers are characterized by lower values of T than are unskilled searchers, Boynton et al.(2).

In Fig. 1, 0 to 15 seconds of search and 15 to 80 seconds of search have been fitted with straight lines as predicted by equation 5. A chi-square test of significance was performed to examine the goodness of fit of the exponential distribution model to the data on Fig. 1. The data from 15 to 80 seconds showed no significant difference from the assumed exponential differences even at the 0.05 level. The limited number of categories between 0 and 15 seconds makes a chi-square goodness of fit test difficult. However, a Kolmogorov-Smirnov test applied to the 0-15 second line indicated a difference from the data which was significant at $>.10$ and $<.05$ level, and a chi-square test also indicated a significant difference from the exponential distribution model.

As an alternative to the Fig. 1 plot, Fig. 2 presents the same skewed data plotted on cumulative logarithmic normal distribution paper. Cumulative log-

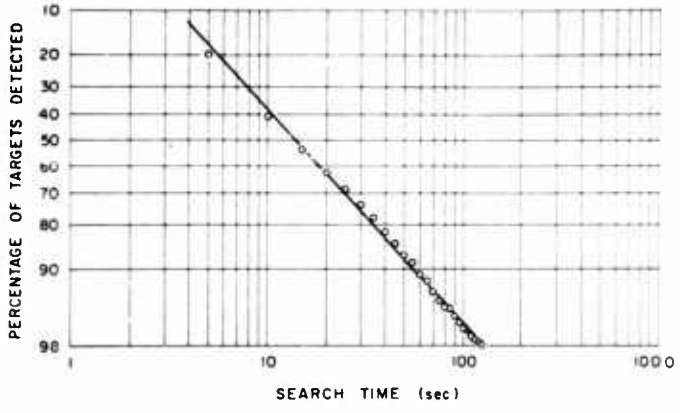

Fig. 2. Percentage of Targets Detected vs. Search Time, N = 1052.

arithmic normal distribution paper is an insensitive index of the underlying distribution since almost any skewed distribution looks straight on this paper, and even a normal distribution for 50 to 100 points provides a fit to a straight line which is deceptively good to the eye. The data on Fig. 2 were subjected to a chi-square test of goodness to fit to the assumed logarithmic normal distribution. The

data were different from the assumed distribution at a level of significance >0.02 and <0.01.

An analysis was made of the mean time to detection for each of the 48 target positions to determine whether position preferences existed. No position preferences were found. In addition, a comparison of mean detection time for the targets detected in the first half hour with those detected in the second half hour of the experiment revealed no significant differences.

Experimental Program, Phase II

Procedure

The experimental room was the Fels Planetarium of the Franklin Institute(5) whose dome dimensions are 65 ft in diameter and 45 ft high in the center. An illumination of greater than 0.01 foot lamberts would have made the structure of this dome visible, and the lower levels of illumination would have approached the scotopic region where search by macular vision would have been impossible.

Five subjects having a minimum of 20/20 vision were used. The subjects were seated in a reclining chair so that they could search the indicated region of the dome in comfort. The center of each search area was 38° above the horizontal. This attention to the subject's comfort caused an unexpected problem. Of an original group of six subjects, one dozed off during some of the sessions, thus limiting the data to five subjects!

The target was 1.2×10^{-4} steradians in size, and the background luminance for the search area was 0.01 foot lamberts. Two search areas were used, one, 0.22 steradians and the other, 0.098 steradians, corresponding to plane angles of 24° x 30° and 10° x 20°. These areas were defined by an auxiliary slide project. The surround was dark, unlike the phase 1 conditions where light spilled over the screen and was reflected throughout the room. Each of the subjects was dark adapted by wearing red goggles for 15 minutes prior to the beginning of the experimental sessions, each of which lasted for one hour. The subjects searched for a total of 44 targets which were randomly positioned in the search area. Three different time orders of target presentation were used for each subject for each of the two search areas.

Alerting, timing and identification of target procedures were the same, as in Phase 1, for the first experiment of Phase 2. In order to compare forced search with self-paced search, this first experiment was repeated and alerting was eliminated. The subject in Experiment 2 was told that at any time during the one hour session there might be no targets or one or more targets; and that these targets could appear and disappear randomly in time and position. Actually, only one target was presented at a time and search times were measured from presentation to detection. Experiment 2 was intended to be more realistic in that the observer's task was to carry out one long search rather than a series of 44 discrete searches. Great care was taken to avoid generating cues when repositioning the projector and creating a new target. Interviews at the conclusion of Experiment 2 revealed that none of the participants had realized that their instructions had been misleading.

Results

The cumulative detection probability for all five subjects combined is plotted at one second intervals in Figs. 3 and 4. The data on Figs. 3 and 4 are not signifi-

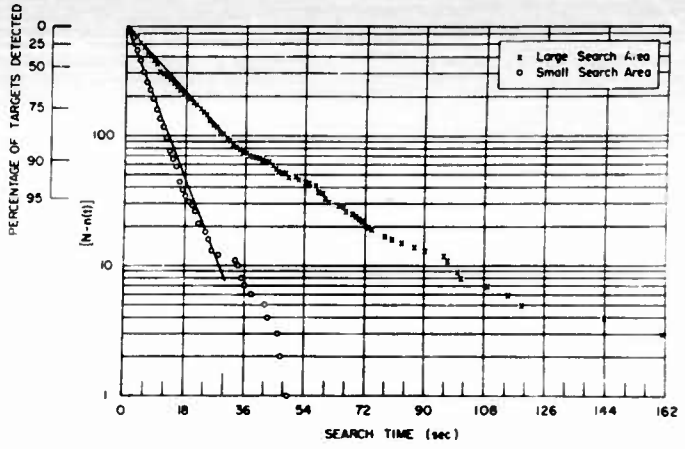

Fig. 3. Percentage of Targets Detected vs. Search Time, N = 660.

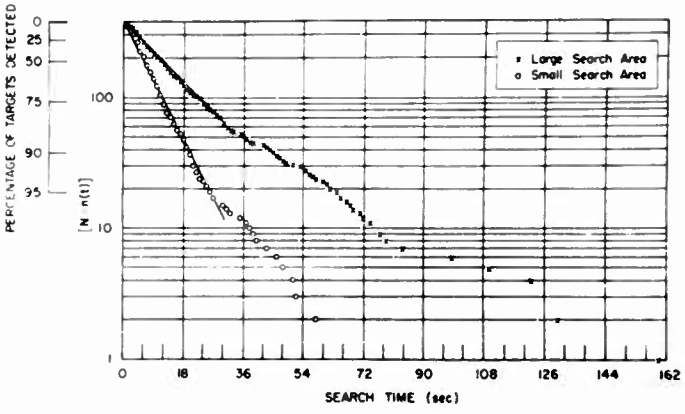

Fig. 4. Percentage of Targets Detected vs. Search Time, N = 380.

cantly different from the fitted line segments as predicted by Equation (5) at as low a level of significance as 0.10.

An attempt was made to fit these data with a cumulative logarithmic normal distribution. The data for the large area, Experiment 1, were significantly different from the logarithmic normal distribution at the 0.001 level and the data for the large area, Experiment 2, were different at >0.02 and <0.05 level of significance.

The data for the small areas of search yield equivocal results for the chi-square test of goodness of fit. These data differ from logarithmic normal distribution at slightly greater than the 0.05 level of significance.

The adequacy of the exponential distribution was demonstrated once again both in a situation where the observer was alerted and where he was not. In addition under experimental conditions which were more closely controlled than in the Phase I experiment, the postulated exponential, distribution did not fail to fit the data for search durations of less than fifteen seconds.

Experimental Program, Phase III

The third and last phase of the experimental program was also the most ambitious. For this reason the procedure and apparatus will be described in greater detail than was appropriate for Phase 1 and 2.

Experimental Design

The effect upon detection time of four independent experimental variables was tested: level of background illumination, target size, contrast, and size of the field of search. Four values of each of the independent variables were used. There were thus 4 x 4 x 4 x 4 = 256 conditions. The values chosen for level of illumination, target size, contrast, and search area size are presented in the following section. Each of the 256 conditions was presented 12 times (3 times per quadrant) to each subject, for a total of 3072 trials per subject. All subjects were tested under all conditions. The experimental sessions lasted one hour.

The dependent variable measured was the time required to detect the target. The method of limits, continuous order, ascending series only (with respect to time), was used. A warning signal was given and the target was projected onto the screen, continuously, until detected, or for a maximum duration of 30 seconds. The first 30 seconds of search were selected so that a detailed examination of the effects, if any, of structure early in the course of search could be examined. In addition to knowledge of *when* the stimulus was to be presented, the subjects also knew the target size for which to search. If the subject reported seeing the target, it was withdrawn, and the subject was required to identify its position, in terms of one of the four (assumed) quadrants. If an incorrect position was reported, the stimulus was repeated until either a time measure for a correct detection was obtained or the stimulus remained undetected for a maximum of 30 seconds.

The four subjects were randomly assigned to conditions, to balance practice and/or order effects. The subjects were dark adapted for ten minutes for both the lowest background luminance, and the smallest search areas of higher background luminances.

To test whether practice effects were significant, a second experiment was conducted. Two groups of 4 subjects were used. Group 1 was composed of the four subjects of the original experiment. Each subject had had 3072 observations during the course of the experiment in addition to his 10 hours of preliminary

training. These subjects comprised the "practiced" group. For Group 2, four men were chosen each with 20/20 visual acuity, one with refractive correction. All were untrained in this type of experimental observation. They were given no training, but were tested immediately.

Apparatus and Choice of Variables

The Phase III experiments were conducted in a room 13½-feet long by 7½-feet wide. On the front wall hung a white screen 84-in. wide by 91½-in. high whose reflectance was approximately 81 per cent.

The background illumination was provided by an Argus 300 projector (4-in. focal length) set at the rear of the room (151.0-in. from the screen). With the largest search areas, the variations in brightness over the surface of the screen were approximately 17 per cent. The surround was dark.

Four levels of background luminance were used: 12.4, 1.03, 0.10, 0.01 foot lamberts. The corresponding intuitive descriptions of the luminance levels are: a very dark day, twilight, deep twilight, full moon. These levels were obtained by the use of a series of Wratten neutral density filters. The Wratten series ranges in density from 0.1 to 4.0 in step intervals of 0.1.

Circular apertures cut out of opaque paper were attached to the selected Wratten filter in the Argus projector to delineate search areas. The subject's eyes were approximately 6 feet from the screen, and the angles subtended by the diameters of the four search areas were 6.8° 18°, 32°, 43°. In steradians, the solid angles were 0.011, 0.084, 0.26, 0.48, determining a range of 44:1 in the search areas.

Small visual targets were projected on the screen by means of a Goldie projector, 7-inch focal length, set at 128.0 in. from the screen. This projector was so mounted that the target stimulus could be positioned accurately in elevation and azimuth anywhere within the search area. The circular target sizes were drilled out of bakelite. The projected areas on the screen were 0.0069, 0.062, 0.20, 0.72 square inches. At the subject's eye, the subtended angles of the diameters were 4.8′, 13′, 24′ and 46′. The corresponding solid angles are 1.3×10^{-6}, 1.2×10^{-5}, 3.8×10^{-5}, and 1.4×10^{-5} steradians.

Four contrasts were used for each of the 16 target size and background luminance conditions. There were, therefore, 64 different contrasts. The ratio of the highest to the lowest contrast in each of the 16 conditions was approximately 2:1.

Blackwell(1) noted that the threshold of subjective observer confidence is approximately the same as the 90 per cent forced choice detection threshold. In consequence, the contrasts selected for this search experiment are, in general, at least twice Blackwell's 95 per cent threshold contrast. The data in the free reporting search situation will, *a fortiori*, be free of false report contamination.

The luminance of the screen for each projector was measured with a Macbeth illuminometer without attenuation of the light by means of filters. A one

degree circular target provided the measurable brightness for target brightness determinations. All measurements were made with this size target and were extrapolated to the actual (smaller) target sizes under the assumption of uniform flux within this area. All measurements were expressed in foot lamberts. Using 0.1 foot lambert as the lowest limit of accuracy of the Macbeth, the transmittance of each Wratten filter was determined. The density of each Wratten filter was measured with a densitometer. These two determinations of the density were in very close agreement. Subsequently, the luminance of the screen produced by each projector without attenuation was measured and all desired levels of background luminance and target luminance were determined by calculation and the use of well calibrated Wratten neutral density filters.

Procedure

There were four subjects, three women and one man, in the initial experiment. All had 20/20 visual acuity with both eyes, two with refractive correction.

The pretraining for these subjects consisted of approximately 10 hours of preliminary testing. During this training the subject was required to detect small circular visual targets of various luminances projected against backgrounds of various luminances. The pretraining search was carried out with contrasts which were approximations to the threshold contrasts for each target size and background luminance which were to be used in the experiment. The threshold approximations were all made with the largest search area, since it was assumed that if they were made with the smaller area, the stimuli would not be detected in the largest search area.

An attempt was made to select the lowest contrast for each target size-background luminance condition such that detection would occur 50 per cent — 80 per cent of the time. This decision was made so that a reasonable search problem could be achieved. Neither instantaneous reports nor low probability watch conditions would have been desirable. Since the dependent variable was the time required for detection, lower percentages of detection were excluded as the number of detected trials would have been too small to be useful.

Results

Practice. A comparison was made of detection time measurements for practiced observers, i.e., the subjects of this experiment and naïve observers. This comparison was made on one of the 64 experimental conditions. The search field was 0.48 steradians, the target's diameter subtended 4.8′, the background was 0.01 foot lambert, and four different contrasts were employed. The Kolmogorov-Smirnov non-parametric test for goodness of fit was used to determine if the two comparable empirical cumulative distributions were significantly different from one another. A significance level of 0.05 was selected, and the test failed to reject the hypothesis that these empirical cumulative distributions came from the same population.

TABLE 1

THE EFFECT OF PRACTICE AND REPLICATION ON $\bar{t}$

Contrast per cent	Naïve Subjects t (seconds) N=96	Practiced Subjects $\bar{t}$ (seconds) N=96	Previous Experimental Data for Practiced Subjects t (seconds) N=48
540	23.5	23.5	22.2
588	9.2	10.6	12.6
864	3.3	4.6	3.4
1078	1.6	1.8	1.6

Detection Time Measurements. The data will be presented in a successive fashion from data gathered on one observer to grand averages over all trials. Figure 5a, b, c, and d are for one subject for the same target and background

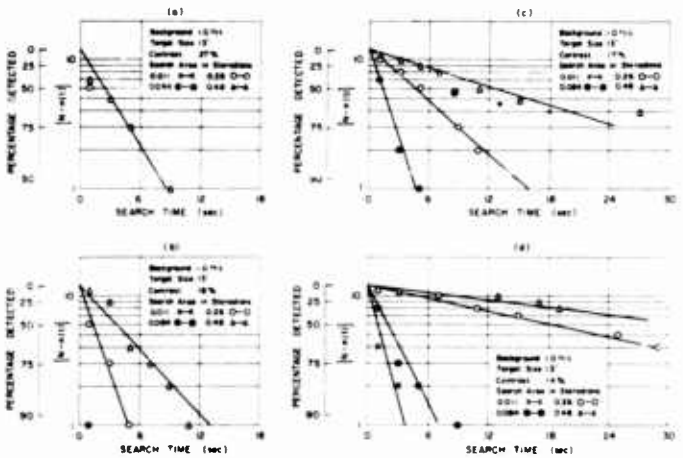

Fig. 5. Percentage of Targets vs. Search Time for Subject C.

luminance but contrasts assumed the values 27 per cent, 18 per cent, 17 per cent, and 14 per cent. All four areas were searched.

Figures 6, 7, 8, and 9 are data averaged over the four subjects, except for Figure 6, which is an average over 3 subjects, and represent typical 48 data point estimates of 16 of the 256 experimental conditions. Each of the curves represents search in a 0.26 steradian field for a target of 13′, for four contrast conditions. Each figure is particular to one of the four background luminances. The discarding of one subject in Fig. 6 was determined on the basis of evidence that her responses on this one day were not representative of her behavior. This is the only instance of discarding data in the Phase III experiment.

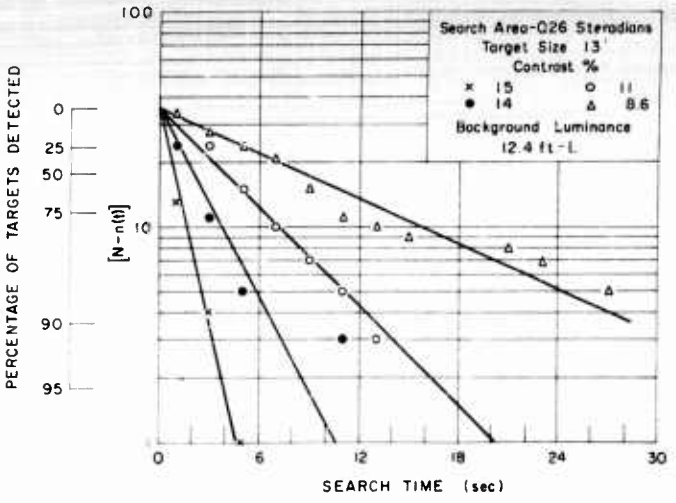

Fig. 6. Percentage of Targets Detected vs. Search Time, N = 36.

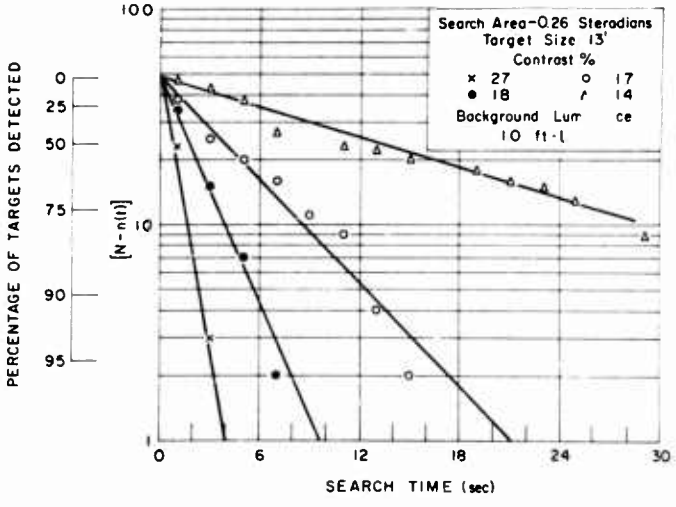

Fig. 7. Percentage of Targets Detected vs. Search Time, N = 48.

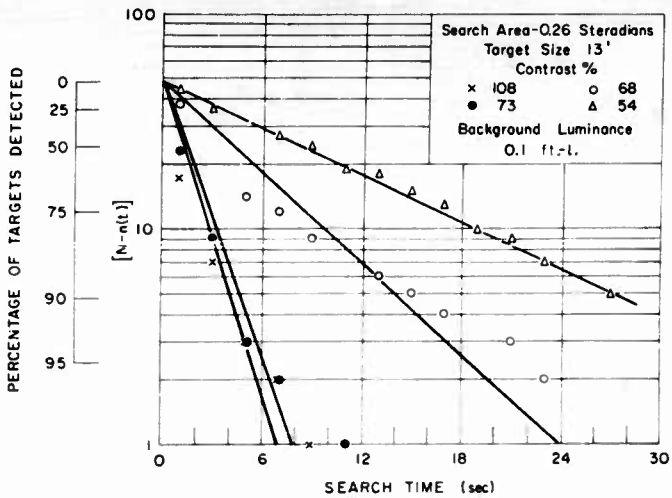

Fig. 8. Percentage of Targets Detected vs. Search Time, N = 48.

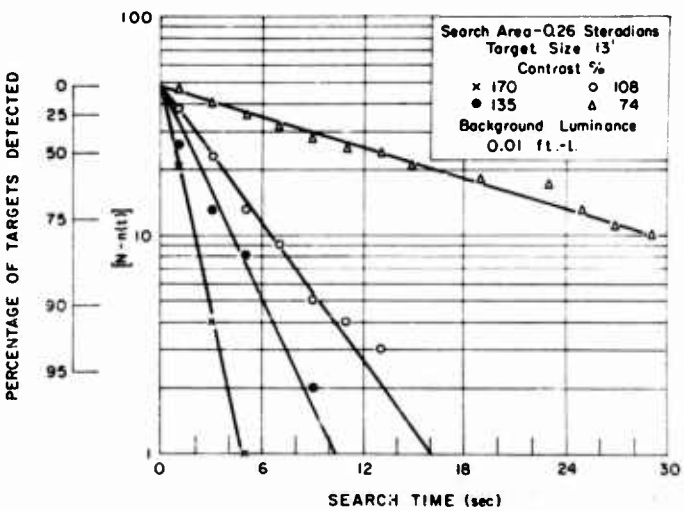

Fig. 9. Percentage of Targets Detected vs. Search Time, N = 48.

Figures 10, 11, 12, 13 are representative curves of the mean time to detection, $\bar{t}=1/m$, as a function of the solid angle searched. Target size and background

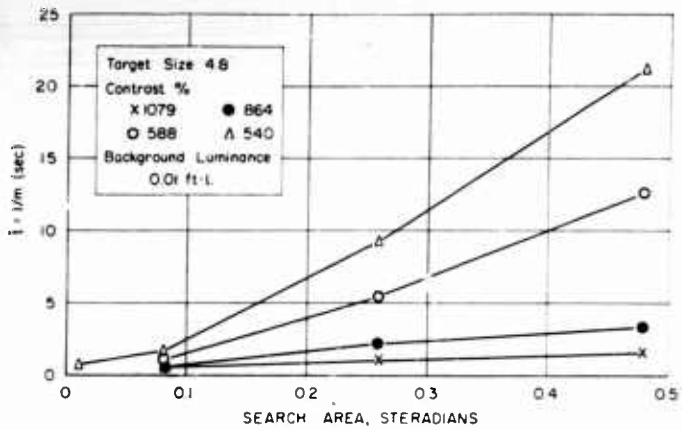

Fig. 10. Mean Time To Detection vs. Solid Angle of Search.

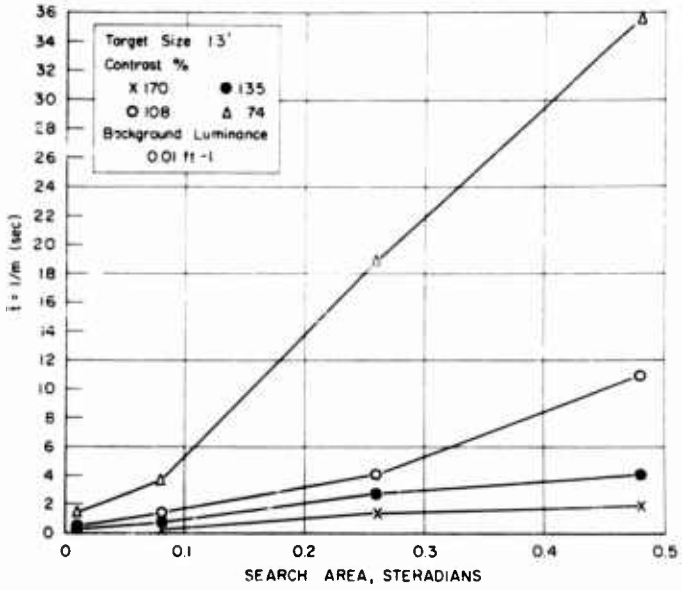

Fig. 11. Mean Time to Detection vs. Solid Angle of Search.

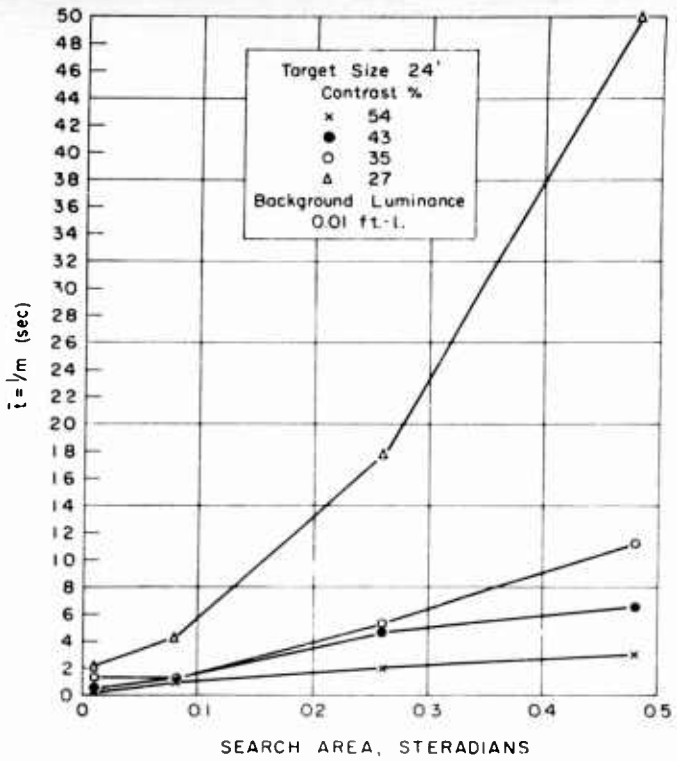

Fig. 12. Mean Time to Detection vs. Solid Angle of Search.

luminance are held constant for each figure, while contrast assumes four values. Details are to be found on the individual legends. Figures such as these constitute the summary data of this experiment.

Figure 14 is a grand combination of data for each search area. The experimental design was such that all targets, luminances and contrast conditions were presented in each of the four search areas. The cumulative distribution function for these data, which is clearly not an exponential distribution, is different from a logarithmic normal distribution at the 0.001 level of significance. Figure 14 is an empirical cumulative distribution for the percentage of targets detected. The median time to target detection, $t_{med} = t_{.50}$, and the time to detection of 75 per cent of the targets, $t_{.75}$, are plotted versus search area on Fig. 15.

Fitted Distributions. A series of 60 additional figures such as Fig. 6 through 9 provided our basic data. All 256 distributions were fitted by eye with straight lines as would be predicted by Equation(5). These exponential distribution fits made to the 128 conditions for the two smallest search angles could not be evaluated easily

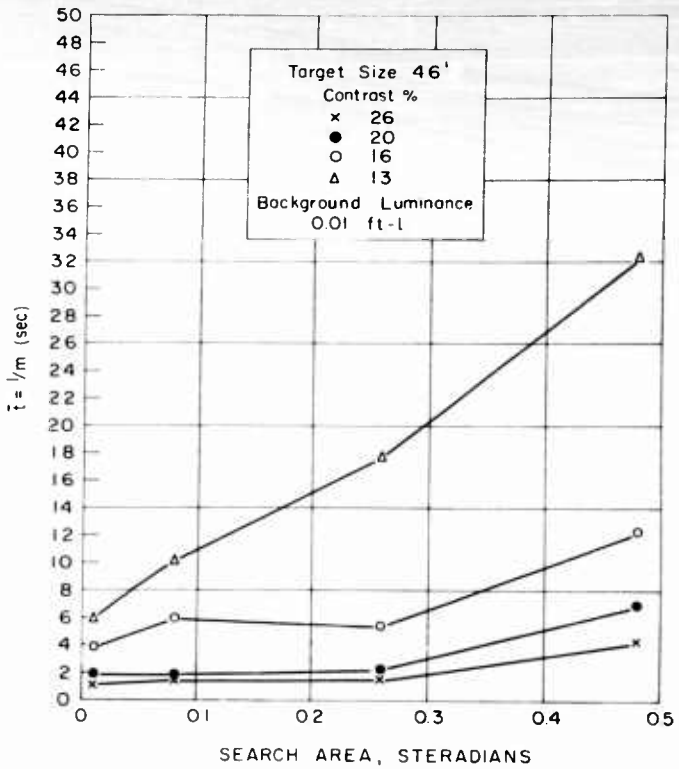

Fig. 13. Mean Time to Detection vs. Solid Angle of Search.

because of the few data points available under these rapid detection conditions. The exponential distribution fits to the 128 conditions for the two largest areas were rated and only 16 were judged "poor." For an example of so-called poor fits, note the fit to the 68 per cent contrast condition on Fig. 8. Of the 16 poor exponential distribution curve fits, 9 or 10 could be acceptable if the intercept conditions were relaxed and a straight line drawn through data for detection times occurring after 4 or 5 seconds of search. A chi-square test showed that seven of these poor fits are significantly different from the predicted exponential distribution. Sixteen of the curves whose fits were judged "good" were randomly selected. No curves in this sample of sixteen differed significantly from the assumed exponential distribution.

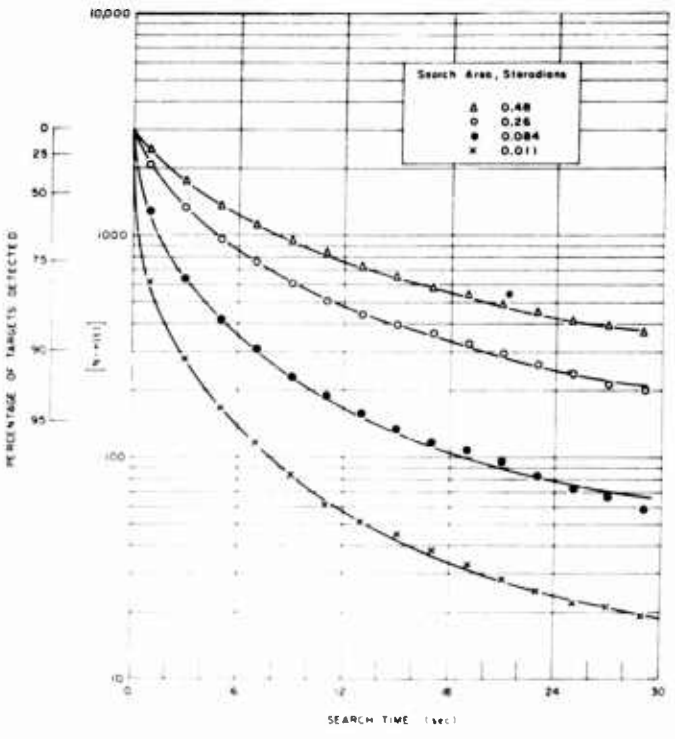

Fig. 14. Percentage of Targets Detected vs. Search Time, N = 3072.

Conclusions and Discussion

The general adequacy of an exponential distribution to describe visual search was demonstrated subject to the following conditions:

a. The interval of time over which search takes place should be limited to about 30 seconds.

b. The defining constraints, i.e., contrast, target size, search field, and background luminance, must remain fixed during the series of trials constituting a measure of visual search.

c. The subject is not instructed to follow a particular scheme for searching.

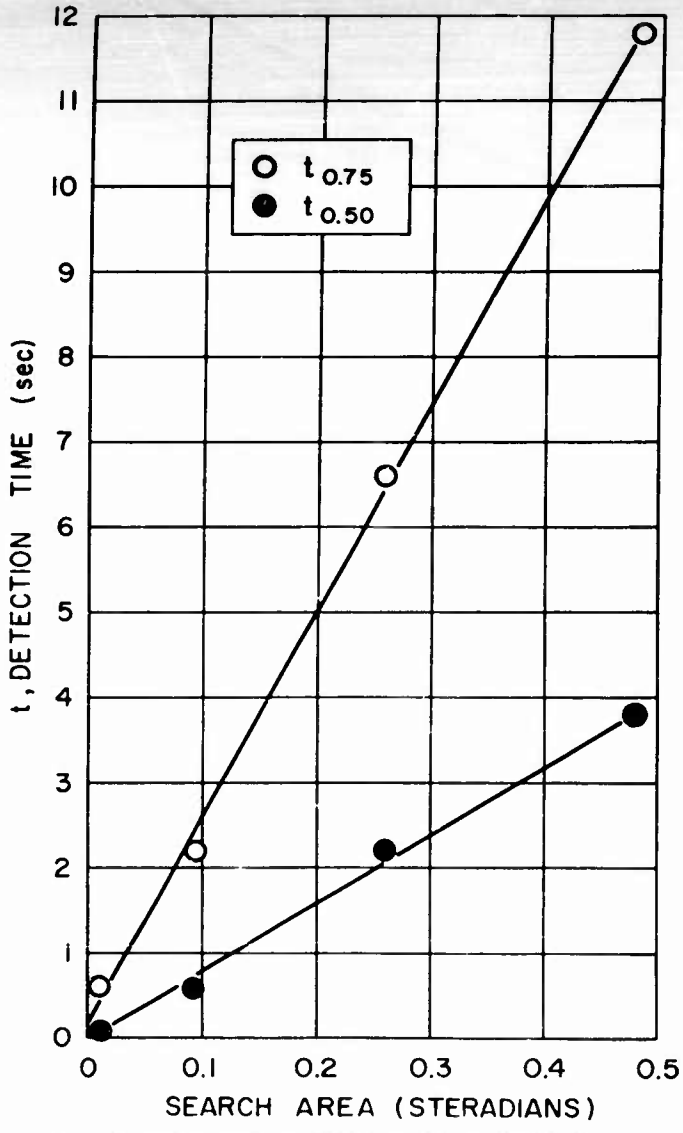

Fig. 15. Time to Detection vs. Search Area Grand Average.

In view of the adequacy of a single parameter distribution to describe visual search data generated under the above conditions, Figs., such as 10 to 13, are representative summaries of the data. These figures present $t=1/m$ for each of the 256 conditions and illustrate the dependence of the distribution parameter, m, on the area under search. For specific problems, within the limits of the variables studied, this area dependence and the simple distribution function for detection under search, aid in determining necessary numbers of men and allocations of search areas for a desired probability of detection. Since the random and independent search implied by the exponential distribution is a lower limit to searching performance, allocations of effort based on this model will be conservative.

The evidence of a variation of m, with search time should be examined by measuring eye positions during search. Such measurements will indicate whether m does in fact change, or if there is a structure imposed by the observer on his search which tends to prevent revisiting searched over areas. These measurements should be of value in establishing training procedures for more effective search.

REFERENCES

1. Blackwell, H. R. Contrast thresholds of the human eye. *J. Opt. Soc. Amer.*, 1946, **36**, 624-643.
2. Boynton, R. M., Elworth, C., and Palmer, R. M. Laboratory studies pertaining to visual air reconnaissance. *WADC tech. Rep.*, 1958, No. 55-304, Part III.
3. Jenkins, H. M. An analysis of vigilance tasks. *MIT Lincoln Lab. Rep.*, 1954, No. 38-6.
4. Lamar, E. S. Visual detection. In B. O. Koopman, *Search and screening*. Washington, D. C.: OEG Report No. 56, Navy Department.
5. Krendel, E. S., and Wodinsky, I. Visual search in an unstructured visual field. AFCRC-TR-59-51 Final Report, ranklin Institute Rep. No. F-A1851, ASTIA No. AD 211156, 1958.

TIME REQUIRED FOR DETECTION OF STATIONARY AND MOVING OBJECTS AS A FUNCTION OF SIZE IN HOMOGENEOUS AND PARTIALLY STRUCTURED VISUAL FIELDS*

JAMES W. MILLER and ELEK LUDVIGH

The visual detection of objects in a homogeneous field has, curiously enough, received little attention. Some of the phenomenological aspects of viewing a totally unstructured field have, however, been investigated(1-4). The refractive state of the eye also has been studied under similar conditions(5-7). Brown has investigated the visibility of stationary black spots over a 17° uniform white field (8, 9). These latter studies were concerned with the relative effectivity of using a collimated reticle as an aid in locating the targets.

In previous papers by the present authors a method was described which provided a means of presenting either a stationary or moving object in an otherwise homogeneous visual field(10, 11). The time taken to locate the target was determined. It was found that a huge amount of variability in the acquisition time existed both between subjects and within a single subject. It was also noted that most observers were at times uncertain as to whether they were seeing the test object or some entoptic phenomenon even when the object was substantially above threshold in size. It further was demonstrated that in the experimental situation existing, misaccommodation is a minor factor in locating objects against a uniform background.

The subjective appearance of the field itself is somewhat difficult to describe. All awareness of depth disappears and one in a sense becomes "immersed" in a foglike atmosphere. Various hallucinatory phenomena are often seen, i.e., gradations of light and shade, rings of different sizes and shapes, etc. The desire to see something tangible becomes increasingly strong and after several minutes a conscious effort must be made to keep the eyes open. The subjective aspects of viewing a homogeneous field have been discussed in greater detail previously(11).

The purpose of the present paper is to present the results of some further experiments concerning the acquisition of simple test objects located in a homogeneous visual field.

Apparatus

The apparatus used to produce the homogeneous field is a clear plexiglas cylindrical annulus (see Fig. 1). The annulus contains a liquid fogging solution through which the observer views a uniformly illuminated white background encompassing approximately 200° visual angle. A wheel and disc type variable speed drive geared to a pulley arrangement is employed to move the targets across about 33 degrees of the available field throughout a wide range of angular velocities (see Fig. 2). The test objects themselves are black plastic spheres of various diameters.

*This work was supported by the Office of Naval Research.

Fig. 1. Front view of fogging apparatus.

The five test objects used in the present experiments subtended visual angles of 10.00, 12.34, 17.45, 29.55, and 59.13 minutes of arc at the nodal point of the eye. The distance from observer to test object is approximately 10 feet. The illumination of the field as measured with a Macbeth illuminometer was 11.88 fc outside the fogged cylinder and 5.52 fc from inside. A more detailed description of the apparatus has been presented earlier(10, 11). Three naval enlisted personnel whose ages ranged from 19 to 23 years were used as subjects. All three subjects possessed

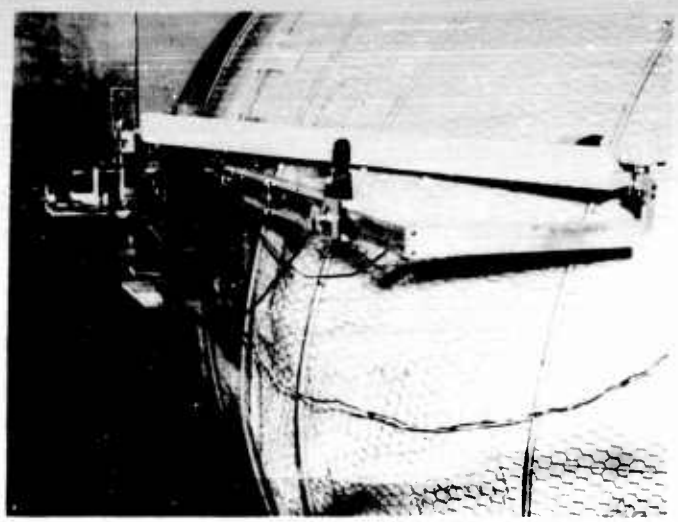

Fig. 2. Control mechanism for presenting targets.

visual acuity of 20/20 or better uncorrected. The visual acuity was also measured with the subject looking through the fogging solution. It was found that the acuity (as measured with Landolt C's) was reduced from 20/20 (1′ of arc) to 20/60 (3′ of arc) by the presence of the fogging solution itself.

Procedure

The subject is seated and the cylindrical annulus, described above, is lowered over his head into the proper position. With the head supported by a chin rest the subject is confronted with a field totally devoid of visible detail. A fan is then turned on which blows air across the inside surface of the cylinder. The subject is told to close his eyes and an assistant experimenter places a piece of white cardboard immediately in front of the cylindrical annulus. One of the five test objects is then placed in position. The subject is instructed to open his eyes and simultaneously depress a switch thus activating a timer. The cardboard is removed at the same time. The task of the subject is to locate the object and to indicate when he has seen it by again depressing the switch, thus stopping the timer. The chief experimenter then moves the test object back and forth from right to left, alternating the directional changes in a random fashion. The angular velocity of the object is in this instance .53°/sec which had been found previously to be substantially above the movement perception threshold. The subject is required to call out the direction in which the target is moving. This procedure is followed in order to establish clearly that it was actually the test object which was seen by the subject. Preliminary investigations had revealed that, even when experienced

observers were used, targets frequently were reported as being seen when in fact there were no objects in the field at all. If the subject correctly named four or five directional changes it was assumed that the real test object had been seen. He was then told to close his eyes and the cardboard was replaced in front of him. The test object was then placed in the next position and the procedure repeated. In the event that the subject should fail to locate the target by the end of three minutes he was told to close his eyes and the trial was terminated.

Three experiments were conducted simultaneously. In Experiment I the target was positioned and remained stationary in one of 29 locations separated by one degree intervals across the field. The height of the targets was always at the approximate eye level of the subject. Both the size and location of the test object were preselected randomly.

In Experiment II the same procedure was followed as in I except that the test object did not remain in a fixed position. After being positioned by the experimenter it was moved slowly across the field in a predetermined direction. The object was allowed to move in the same direction until it almost reached the edge of the field, whereupon, if the subject had not yet located it, the direction of movement was reversed. The object was moved at an angular velocity of .14°/sec which had been found previously to be below the threshold of movement perception under the experimental conditions imposed.

The procedure in Experiment III was the same as in Experiment II with one exception. Two vertical black lines, 1.4 mm thick, were located approximately 15 inches in front of the subjects' eyes. They extended from the top to bottom of the field. Their angular separation was 11.04 degrees which in effect divided the useable target space into thirds. The reason for inserting these lines was to determine whether or not structuring the field to this extent would alter in some way the responses made by the subject.

Five target acquisitions were determined for each experiment in a random order. The order of the experiments themselves also was randomized. Other than when the black lines were visible, the subject was unaware as to which procedure was being followed. To the best knowledge of the experimenter the subjects never knew that the procedure was varied other than when the black lines were used.

Two target acquisitions were determined at each of 29 positions, for each of five target sizes. This was accomplished under all three experimental conditions, requiring approximately twelve, one-hour experimental sessions.

Results and Discussion

The results of determining the acquisition time of three subjects are shown in Figs. 3-6. It is seen in each of these figures that as the size of the test object increases, the length of time required to locate it decreases. The same general relationship appears to hold for all three experiments for each of the three subjects. In these figures the acquisition times for each subject have been grouped by target size irrespective of the position of the target in the field. The points plotted as circles in Figs. 3-5 represent the mean of 58 acquisition trials.

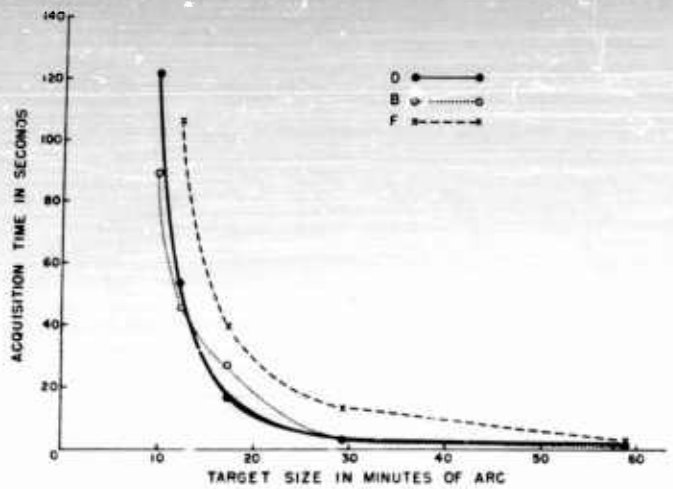

Fig. 3. Acquisition time of three subjects obtained in Experiment I.

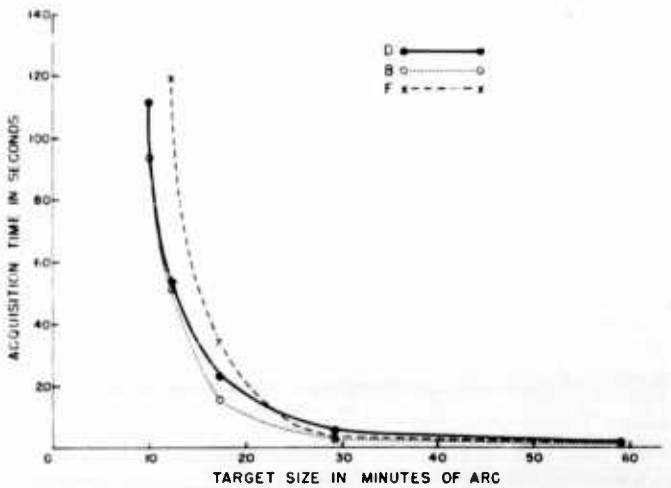

Fig. 4. Acquisition time of three subjects obtained in Experiment II.

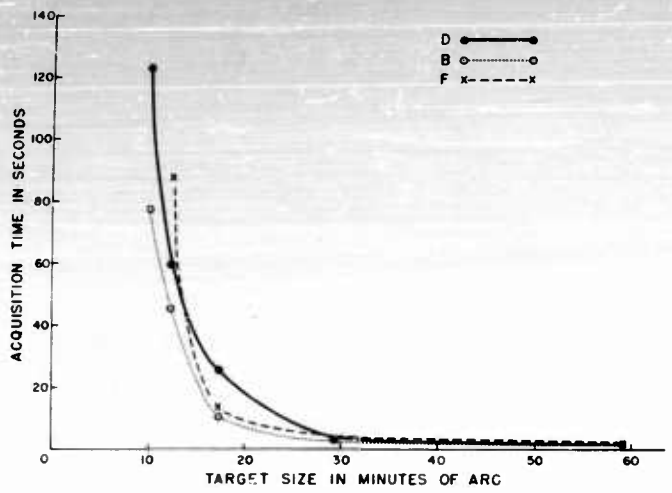

Fig. 5. Acquisition time of three subjects obtained in Experiment III.

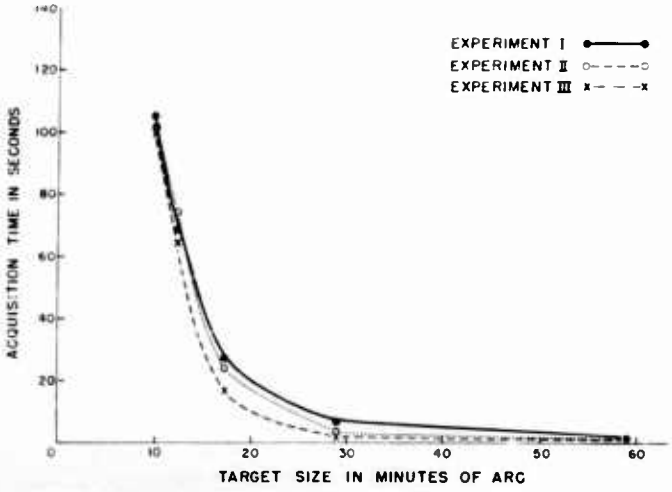

Fig. 6. Mean acquisition time of three subjects for Experiments I, II, and III.

It is apparent that the acquisition time begins to increase rapidly when the size of the target is less than approximately 20′ arc. This is indeed surprising in view of the fact that when the visual acuity was measured through the fogging solution it was found to average 20/60 (3′ arc). It should be borne in mind here that the maximum time allotted for observation is three minutes and therefore the times shown for the smaller targets are reduced artificially. That this time limitation is indeed a major factor can be seen readily by examining the frequency distributions of the individual targets as shown in Fig. 7. It is apparent here that

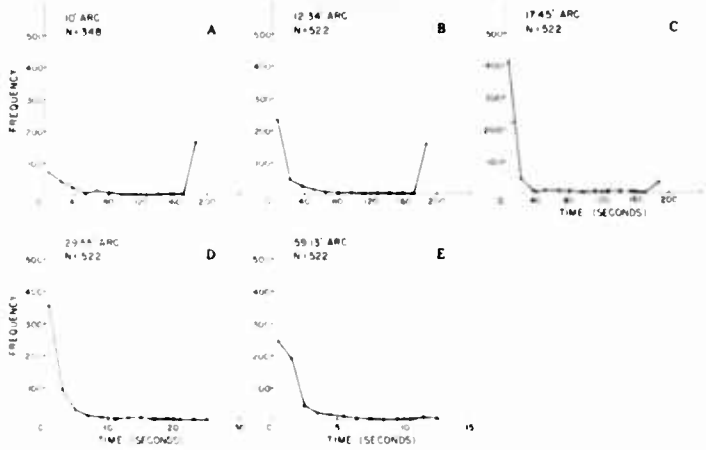

Fig. 7. Frequency distributions of individual targets for Experiments I, II, and III, combining the results of 3 subjects.

the subject never did locate the two smaller test objects (A, B) a substantial percentage of the time. The probability, thus, of finding the test object in any given time interval (Δ t) continually decreases. This is true even for an object subtending 17.45′ arc or almost six times the measured acuity threshold value. These results are consistent with the comments of these and other subjects. The general feeling was that, "the longer one is exposed to a uniform visual field the more disoriented you become."

As stated earlier, all test objects in these experiments were placed on a line approximately level with the eyes. However the subjects soon become unaware as to where they are looking. It has been shown by Irvine and Ludvigh, Ludvigh, and others, that the eye substantially lacks position sense and that in the absence of differential retinal stimulation the individual does not know the position of his eyes(12, 13). There is, thus, a certain element of chance involved in locating a target in a totally homogeneous visual field. Not only has the individual no accurate knowledge as to where he is looking but in addition has no cues as to where he has searched previously. In Experiment I, in which the target remained in a fixed position, researching an area searched previously was completely without

value. In Experiment II however, researching the same area would be of some benefit because the test object could have moved into it after a previous search had occurred. Inasmuch as the subjects in these experiments did not know whether the test object was moving or not, there is no reason to believe that the manner in which they searched was different for the two conditions. The results of Experiments I and II, as shown in Fig. 6 demonstrate clearly that there is no substantial difference in the acquisition times obtained under the different conditions. If the subjects were able to search efficiently in a prescribed pattern, one might expect that the target would, on the average, be located sooner when it was stationary than when it was moving. Inasmuch as the results for the two experiments are almost identical, one must suppose either that the subjects searched in a totally randomized manner or that they attempted to search systematically but were unable to do so. It seems unrealistic however to assume that there is any such thing as a totally randomized search even in an unstructured field.

Interviews with subjects during and after these and other experiments have revealed that there is a great deal of variation in the methods of search used in locating the test objects. Most subjects search in some sort of a prescribed pattern or at least this is their stated intent. The results show clearly that efficiency of search in an unstructured field is quite low as compared to that in a well structured field.

This gross inefficiency of search yields results which are extremely variable. That is on one trial, a given size target may be seen almost instantly upon opening the eyes and on a subsequent trial it may not be seen at all in the allotted time. In addition to this, the target will sometimes fade out before it can be ascertained whether or not it was the real object which was seen. Standard deviations have been computed from the data shown in Fig. 7 and were found to be so large as to be meaningless. Consequently a method was devised which, in addition to yielding further information about the data, provides a means of comparing the results of experimental conditions, individual differences, etc.

Now if one assumes that the search is carried out in such a manner as to utilize discrete search acts there is a probability (p), that the test object will be detected in a single search act. If the object is not located in the first such act this constitutes a failure (q), if not in the second search act, another failure, etc. If the object is detected on the nth act, that act constitutes a success and terminates the trial. In view of the fact that a success terminates a trial, the problem is in determining the probability of the detection occurring in a given interval of time. The total time required to locate the object has been referred to as the acquisition time $(t-r)$ with r=reaction time. Let s=time taken for a single search act. The number of searches made (n) is $n=\frac{t-r}{s}$. If the probability of success in a single search is p and of failure $q=1-p$ then the likelihood, P, of success on exactly the nth search is $P=q^{n-1}\cdot p$ or $q^{n-1}(1-q)$ or $q^{n-1}-q^n$, $P=q^{\frac{t-r-s}{s}}\cdot(1-q)$. Let reaction time $(r)=.2$ sec and let the time taken for a unit search $(s)=.8$ sec.

Values of p can thus be determined for individual targets, subjects and experimental conditions. However in order to compare various groups of data it is necessary to utilize the standard error of this p. The standard error of p was computed as follows: a value of p, the mean (M) and the standard error of the mean (σm) are computed. This σm is then added to each score and a new p is computed. The difference between this p and the original p is the σp.

Figure 8 shows the frequency distributions of two different size test objects for one subject. The observed frequencies have been grouped and plotted as bar

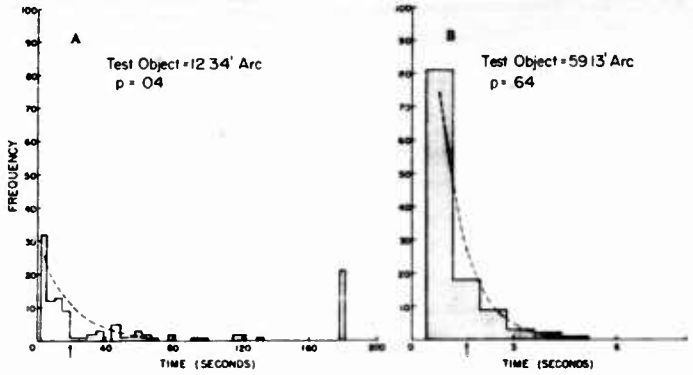

Fig. 8. Observed frequency distribution (bar graph) and theoretical distribution (dashed line) of Subject D for two different size test objects.

graphs. The dashed lines represent the theoretical frequencies obtained using the concept of p. The discrepancies between the observed and theoretical values were examined using chi-square and were found to be not significant for either of the test objects shown.

As mentioned earlier it appears that search in an unstructured visual field is grossly inefficient. If search under such conditions could be made systematically, then it would be possible to divide the field into a number of specific areas. The object of search then could be located ultimately by exhausting the areas one by one. For the sake of brevity let us call this method exhaustive search. The frequency distribution would in this case not have the long tails shown in Fig. 8 but would be flat, inasmuch as the probability of locating the object would be the same in any given search act. To illustrate further, let us assume that a given visual field has ten specific regions. If $p = .10$, the probability of locating the object in the first search act is .10, and q, the probability of failure is .90. There remain now only nine regions to be searched. The probability of locating the object in the second search act is also .10 (1/9 or p on the second search act $\times$ .90 or q on the first search act). The probabilities on the succeeding search acts are computed in the same manner.

Indeed it can be shown that if $p = .04$, as in Fig. 8(A), all the test objects should have been located in twenty-five search acts ($25 \times .04 = 1.00$) if the subject

could utilize the exhaustive search method or in some way be prevented from researching an area searched previously. Using the assumption that a single search act(s) requires .8 seconds this means that all the test objects should have been located at the end of 19.2 seconds as shown by the arrow. The comparable point on the graph of the 59.13′ arc test object is similarly indicated by an arrow. The value of p in this latter case in .64. This means that objects of this size should be detected before completion of the second search act (1.6 seconds). It is obvious that an hypothesis incorporating the assumption of a systematic, exhaustive search does not fit the experimental data and that the search is either tremendously inefficient or random. More than likely it is a combination of these.

Figure 9 shows the values of p plotted as a function of target size for three subjects. It is readily apparent that as the size of target increases, the probability

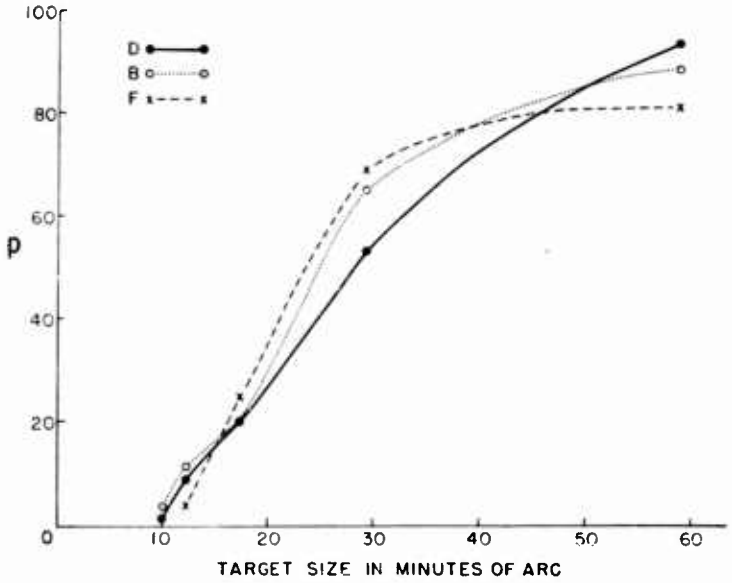

Fig. 9. Probability of detecting the test object in a given search act (p) as a function of target size for three subjects.

of locating it in a given interval of time or search act increases. Recalling that the visual acuity of these subjects determined under the experimental conditions was approximately 3.0′ arc, it is interesting to note in Fig. 9 that when searching in a homogeneous field the angular subtense of the target must be increased by a factor of ten over the measured visual acuity threshold in order to be located in a relatively short period of time.

REFERENCES

1. Metzger, W. Optical investigation of the Ganzfeld. II. Concerning the phenomenology of the homogeneous Ganzfeld. *Psychol. Forsch.*, 1930, **13**, 6-29.

2. Gibson, J. J., and Waddell, D. Homogeneous retinal stimulation and visual perception. *Amer. J. Psychol.*, 1952, **65**, 263-270.

3. Cohen, W. Spatial and textural characteristics of the Ganzfeld. *Amer. J. Psychol.*, 1957, **70**, 403-410.

4. Hochberg, J. E., Triebel, W., and Seaman, G. Color adaptation under conditions of homogeneous visual stimulation (Ganzfeld). *J. exp. Psychol.*, 1951, **44**, 153-159.

5. Whiteside, T. C. D. Vision in an empty visual field, a subjective technique for the measurement of accommodation. Cambridge, England: Flying Personnel Res. Comm. RAF Inst. of Aviat. Med., 1953, Rep. No. 850.

6. Westheimer, G. Response of the accommodation mechanism to visual stimuli. Proj. No. NONR-495(09), NR 140-105, Tech. Rep. No. 1. Columbus, Ohio: Ohio State University Research Foundation, 1956.

7. McCulloch, C., and Turnour, N. C. The influence of refractive state on vision in space. Toronto: R.C.A.F. Inst. of Aviat. Med., 1956, Rep. No. 56/2.

8. Brown, R. H. The effectiveness of a collimated reticle as an aid to visual detection of aircraft at high altitude. *USN Res. Lab. Rep.* 1956, No. 4863.

9. Brown, R. H., and Carl, J. M. Visibility in an empty visual field. USN Res. Lab. Rep., 1958, No. 5072.

10. Miller, J. W. A review of the methods previously employed to produce a homogeneous visual field and the description of a newly devised technique. USN School of Aviat. Med. Proj. NM 17 01 99, Subtask 2, Rep. No. 14, 1957.

11. Miller, J. W., and Ludvigh, E. Visual detection in a uniformly luminous field. *J. Aviat. Med.*, 1958, **29**, 603-608.

12. Irvine, S. R., and Ludvigh, E. J. Is ocular proprioceptive sense concerned in vision? *Arch. Ophthal.*, 1936, **15**, 1037-1049.

13. Ludvigh, Elek. Possible role of proprioception in the extraocular muscles. *Arch. Ophthal.*, 1952, **48**, 436-441.

THE RELATION BETWEEN THE NATURE OF THE SEARCH SITUATION AND THE EFFECTIVENESS OF ALTERNATIVE STRATEGIES OF SEARCH

ROBERT GOTTSDANKER

Search is resorted to only when necessary. If, for some reason, an object of signal cannot be located immediately the process of search is undertaken. What factors determine whether search will be required? Let us call these factors *Search-determinants.*

Interposition: An object cannot be located because something else blocks it from view. The interposition may be complete or partial.

Smallness: The signal may be hard to find because it covers such a limited area. Perhaps it is so small that it eludes discovery even when the total area of possible location is not large. On the other hand a larger object may require search if the total area is large.

Weakness: An object which covers much of the visual field often is not seen at first if it contrasts only slightly with a background. Heightened contrast does not guarantee immediate detection if there is local instability in energy levels, i.e., if there is noise in this dimension.

Distortion: An object may fail to look like itself. This may come about because the perspective deformation is not evaluated correctly. Even a difference in orientation, such as seeing something upside-down may cause trouble. Under natural conditions, another cause of distortion is variation in density of the medium through which the light travels. In instrumental viewing there are many reasons for non-linearity.

Imbeddedness: In camouflage the contours of an object are destroyed by providing stronger inner contours which are like those of the surroundings. Also, if the actual contours of the object are continuous with, or are not distinct from other contours in the field, it is difficult to make the object emerge perceptually from the background.

Competition: There may be no problem at all in regard to detection, but considerable of one in regard to discrimination. Finding a particular face in the sea of faces requires search. The more similar the faces, the more difficult will be the search.

The term *search-situation* is applied to those circumstances necessitating search. It is possible that search is required because of the operation of only one of the foregoing search-determinants. It is more likely that several are working in combination. The task may involve finding a small, weak, signal that is like many other small, weak, signals.

It appears that there are two main *search-goals.* There may be the goal of finding a specific object or a class of objects. On the other hand the task may be as general as the reporting of anything out of the ordinary or suspicious.

It is natural to be interested in *search-techniques*. Since the causes cannot be eliminated, the methods for coping with the situations are of prime importance. Techniques may be divided into two categories. First, there are *aids* such as sector markings and magnification of limited areas. Second, there are the *strategies*. Should a scanning method be used or will a steady gaze help perceptual emergence? When possible, should the searcher move in relation to the scene? With several classes of objects to locate, should separate observers look for the different classes?

Despite the diversity of search-determinants: interposition, smallness, weakness, distortion, imbeddedness, and competition, it is possible that search situations may be reduced to the same formal terms for description and prediction. However, mathematical descriptions of the similarity of competing forms are not obvious nor is, for example, the degree of perceptual imbeddedness. Further, it is not clear of how predictions of performance may be made without stipulating the techniques to be followed. Further, the situation is complicated by the probability that there is a difference in effectiveness of techniques according to the determinants involved in a search situation.

If one must see behind objects, it is obvious that he must change his position in relation to them. For small, or weak signals, this could hardly be an advantage. Magnification, sector scanning, and grid lines should prove helpful for small signals but might be detrimental for finding large weak signals. Class-by-class searching may be a satisfactory method when the reason for search is competition among like objects but may be severely detrimental when the task is that of finding objects which are perceptually imbedded. It is not even meaningful when the goal is to report anything peculiar. These considerations provide the backgroun ' of an experiment the investigator undertook with the help of his class in Experimental Psychology.

In the experiment to be described, the subjects (college students) were given the task of finding all of the objects in a projected slide which were the same as those drawn on their answer sheets. Two search-situations were used. The first was characterized by competition. There were the search objects to be found and a large number of decoys. All were seen on a uniform background and all contours were clear and separated. The second search situation was characterized by imbeddedness. No other objects were present which looked like those to be found. On the other hand, the background was broken up in such a way that the detection of objects was difficult. Also, the objects were not all flat in respect to the frontal plane as in the competitive case. For both situations the same number of classes of objects and number of objects in each class were to be found.

The search objects were stylized silhouettes of different breeds of dog: collie, dachshund, poodle, and spaniel. They were made more similar than they are in nature. Figure 1 shows an answer sheet, with a subject's marking indicating where he found each dog and its orientation. By requiring the orientation to be shown, the probability of making a correct choice by guessing was greatly reduced. Figure 2 gives an example of a competition-situation. There were 16 objects to be

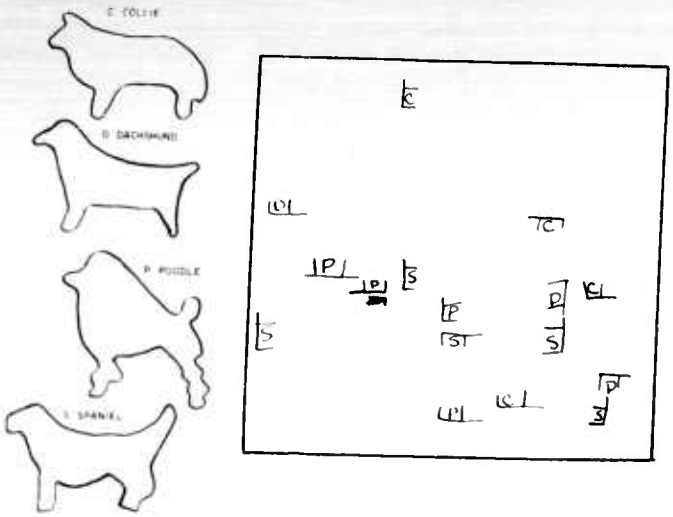

Fig. 1. Example of an answer sheet.

Fig. 2. A completion-situation slide.

found, four of each class. In addition, there were 36 decoy objects, 9 for each class. These were made up of 3 examples in each of three sub-classes. The assignment of loci and orientations was determined by a random procedure.

Figure 3 shows an imbeddedness-situation. As you can see the cut-outs are strewn over a scrap lumber pile. In the experiment proper, the subject had four

Fig. 3. An imbeddedness-situation slide.

slides of each type to search. On two of the four slides he was given a prescribed method of search: first find the four collies, then the four dachshunds, then the four poodles, and finally the four spaniels. This is called the sequential strategy. On the other half of the slides, the subjects were allowed to use any strategy they desired. This may then be called the optional strategy.

Four groups of subjects were tested. There were ten subjects in each group. A counter-balanced design was used so that each slide was used by an equal number of subjects for the sequential strategy and the optional strategy. Further, each slide occurred equally often in the first half and in the second half of the trials. It should be added that there were four practice trials, comprising each of the possible combinations of situation and strategy.

An experimenter was seated next to each subject. As soon as a slide was first flashed on the screen, a tape recording was started on which there was a count-up

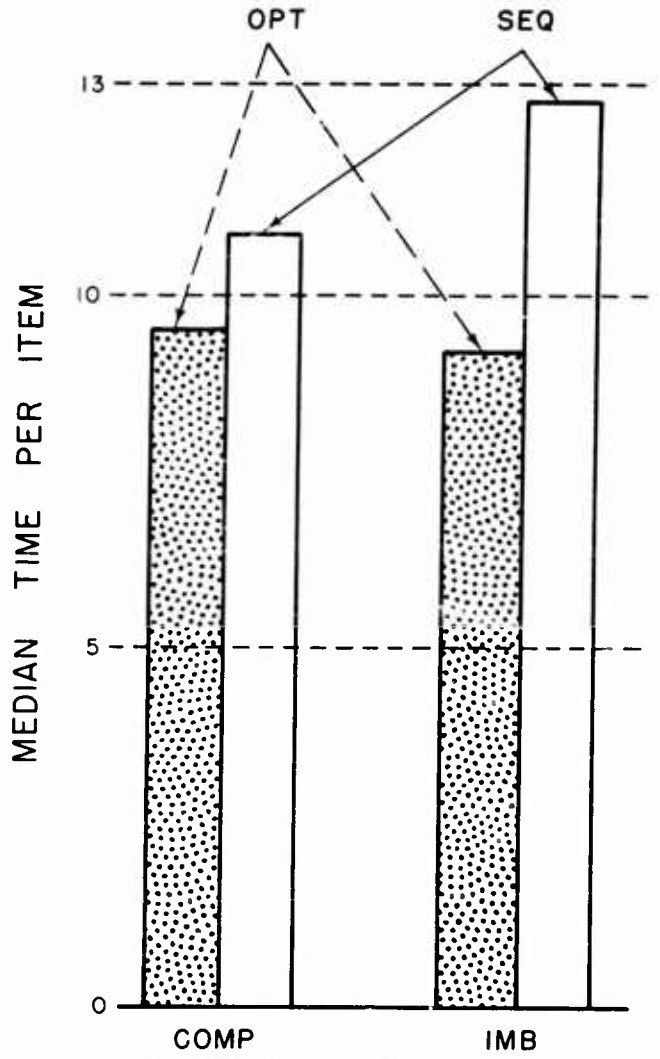

Fig. 4. Median time for finding items.

of seconds: one, two, three, etc. Every time the subject marked a location on his answer sheet, the experimenter wrote the elapsed time on his duplicate answer sheet. The time limit was 180 seconds.

Each trial was scored in terms of the median number of seconds required to find each search object. That is, the time interval between one location and the next was determined, and the median time for all of the intervals was computed.

Results are summarized in Fig. 4. It is seen that for the competition-situation, there is some advantage in the free strategy over the sequential strategy, the mean difference being 1.3 seconds per item located. However, the difference is much greater for the imbeddedness-situation, the difference being 3.6 seconds per item located. This interaction proved significant in the analysis of variance at the 1 per cent level for the one-tail test, and at the 2 per cent level for the two-tail test. It should be noted that the number of cases was reduced from 40 to 30. This is because of the refusal of 10 subjects always to use sequential search when so directed. Also, there was some complexity to the analysis because of differences in difficulty among the imbeddedness slides. Fortunately the experimental design provided protection against both of these contingencies.

Thus it has been demonstrated that the relative effectiveness of a strategy of search depends upon the determinants that necessitated search. For at least the situations tested, it also appears that sequential search is not a particularly effective strategy. It should be noted, however, that there were eleven cases where subjects used this method voluntarily when the strategy was optional. All occurred with the competition-situation. Here is another behavioral difference between the situations. Yet another is found in the analysis of errors. In the competition-situation the percentage of errors for optional and sequential search was 15 and 16 respectively. In the imbeddedness-situation the corresponding values were 5 per cent and 4 per cent. It is at least a little surprising that subjects worked as quickly in the competition-situation as in the imbeddedness-situation, even at the cost of many more errors.

Following is a case where knowledge regarding the ineffectiveness of class-by-class search might prove useful in making a decision regarding strategy. Suppose there are four areas to be searched, four classes of object are sought, and there are four people to do the searching. Should we assign one observer to each area to look for all four classes of object or should we have four observers look at the first area, each being responsible for one class, then have them move on to the second area, and so on? Present results indicate that each should be responsible for all classes in one area.

NATURAL TENDENCIES IN VISUAL SEARCH OF A COMPLEX DISPLAY*

JAY M. ENOCH

This brief discussion covers some of the salient points uncovered during an extensive study made of visual search conducted at The Ohio State University. These data were collected in a series of eight experiments which have been reported in eleven separate reports(1-11). The reader is referred to these for greater detail and greater understanding of the experimental designs and techniques employed.

In these studies two classes of observers, and two types of observation material were used. Trained photointerpreters viewed aerial photographs of varying scale and verticality, and non-trained observers viewed aerial maps simulating aerial photographs. The non-trained observers were drawn from the staff and students of The Ohio State University. A modified ophthalmograph was employed† in most of the studies in this series. Where additional information was needed, or validation was desired by a second method, performance measurements were obtained as indicated in the individual studies. Thus, the bulk of these data are in the form of eye movement and eye fixation records which provide information as to the location of the eye and the time course during search for a given object or class of objects on a given display.

Turning now to an analysis of the records obtained, the first point that one notices is the fact that the search pattern is divided into at least two phases. The first phase we might call an orientation phase. During this phase the observer goes through a characteristic pattern in his search, which is repeated with remarkable similarity in every pattern executed by the same individual. One might call this, the individual's basic, or general search pattern. Figure 1 shows the first five eye movements and eye fixations of one individual on eight successive records, each display having had a different physical quality, content, scale, etc. The pattern followed by this individual was essentially a crisscross one which could be seen as these patterns developed. The only variable found to influence this phase of search, was familiarity with the subject material. The simpler and more familar the material, the shorter was the orientation phase, but it could always be identified. An important point to note is that no record was obtained wherein the subject read the photograph as he might read a book. This is a popular mis-conception. It is particularly on this point, that the investigator can be led astray by subjective report of the pattern followed by the observer. Most patterns were of

*Work discussed in this paper was conducted at the Mapping and Charting Research Laboratory of The Ohio State University Research Foundation as part of the project on *Human Factors in Photographic Interpretation*. Dr. Enoch retains a connection with that program as consultant. Dr. Glenn A Fry serves as supervisor. This work was supported by a contract between the Rome Air Development Center, Griffiss Air Force Base, New York, and The Ohio State University Research Foundation.

† A standard ophthalmograph had been previously modified by Dr. Glenn A. Fry to allow determination of the position of a single eye at any time in both the x and y planes during fixation of a display.

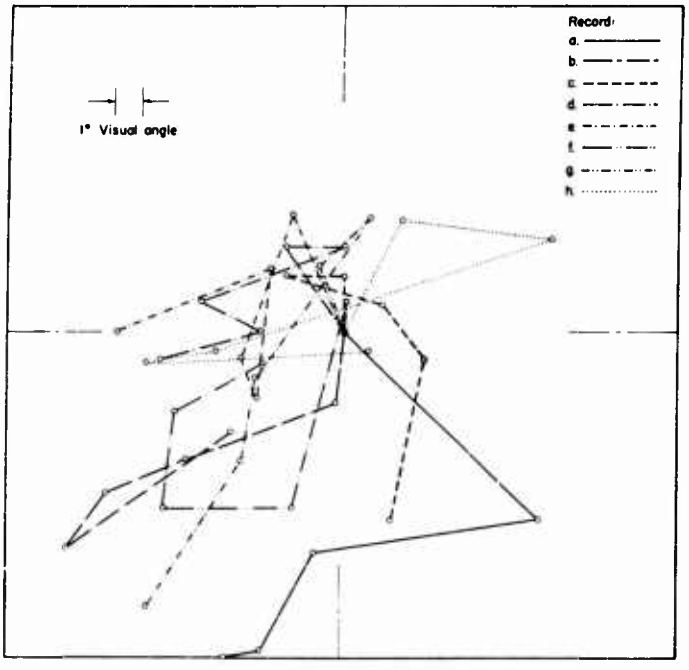

Fig. 1. Initial five fixations of Subject W.P. on eight successively analyzed records having different scale, content, and given target.

the following natures, spiral (inward or outward), up and down, laterally back and forth starting either at the top, or at the bottom, a closing square pattern, etc. These are not listed in order of frequency and no one pattern was found to dominate. Some individuals did use what might be called a non-directive pattern, i.e., the experimenter could not detect the nature of the figure being completed by these observers. These were not in any sense random because of the nature of the distribution of the eye fixations.

At the end of the orientation phase of the search, the individual would move on to a second, or what might be called a specific search phase. If he had any cues or clues as to the location of that object or group of objects for which he was searching, he would proceed to utilize these immediately after completion of the orientation pattern. If he did not have such aids to the location of the object, he would tend to expand upon the basic search pattern started in the orientation phase. What often proved disturbing to the experimenters was the fact that if the object which was sought by the subject was not in close relation to those factors which might be interpreted as cues and clues, he would very rarely look at the remainder of the picture (which would sometimes include areas covering greater than fifty per cent of the display) prior to declaring that the object sought did

not exist on the display. It should be noted that there were some few observers who did revert in these instances to their basic, or general search patterns. This, of course, raises the entire question as to the parameters entering into the decision to end search which is a separate discussion in and of itself.

Turning now to a second facet of the analysis of these data, it was noted consistently in all eight studies, and under all conditions employed, that marked non-uniformities of coverage of the display were evident. First, it was noted that for some reason not immediately evident, the upper left hand quadrant of the display received considerably less attention than the lower right hand quadrant while each of the other two quadrants received about an intermediate degree of attention. This finding is contrary to the findings obtained by other investigators working in areas dealing with either art, or advertising media. Thus, one might say that on these types of display used in these experiments there was a shift in attention toward the bottom half of the display and toward the right hand half of the display.

Of considerably greater importance, was the fact that if one studied the distribution of eye fixations as a function of the radial distance from the center of the display, it was found that there was a marked concentration at the center of the display, with the edges or border (peripheral) regions of the displays essentially ignored. Figure 2 is a sample set of data from one of the earlier studies showing this phenomenon. It has been shown that this finding is not dependent upon the size of the display, the quality of the display, the time allowed for study of the display, the generality of the problem given the observer, or upon the content of the display. The same function was obtained using both trained photointerpreters, and non-trained observers. It was found that for large displays, that is, displays over 25 degrees in diameter, that the function tended to reach an asymptote in the region of the larger angles. If one studies the distribution at the very center of the display one finds for other than very small displays that there is also an asymptote of the function for regions within one degree of the center of the display. These same findings were demonstrated in a separate study designed to determine performance of observers searching for a class of objects on a very large display. Since in the process of photointerpretation, the observer is almost invariably looking for objects which are of a dimension such that it is virtually necessary for him to fixate these objects with his central retina, it is evident that this natural tendency in search must be overcome. It is felt that this tendency can be overcome by means of training, and/or the use of some automatic scanning or indexing device.

In relation to this type of finding, it should be noted that if one desires to concentrate attention in a given region of a display, this can be achieved by decreasing the size of the display. One does obtain a higher concentration in attention in terms of a greater density of fixations per unit area and increased durations of fixation by such a technique, but at the same time one loses markedly in overall efficiency by reducing the size of the display. In this sense, efficiency is defined as that percentage of total central eye fixations falling within the area of the display itself. Figure 3 shows the percentage of eye fixations falling outside of the

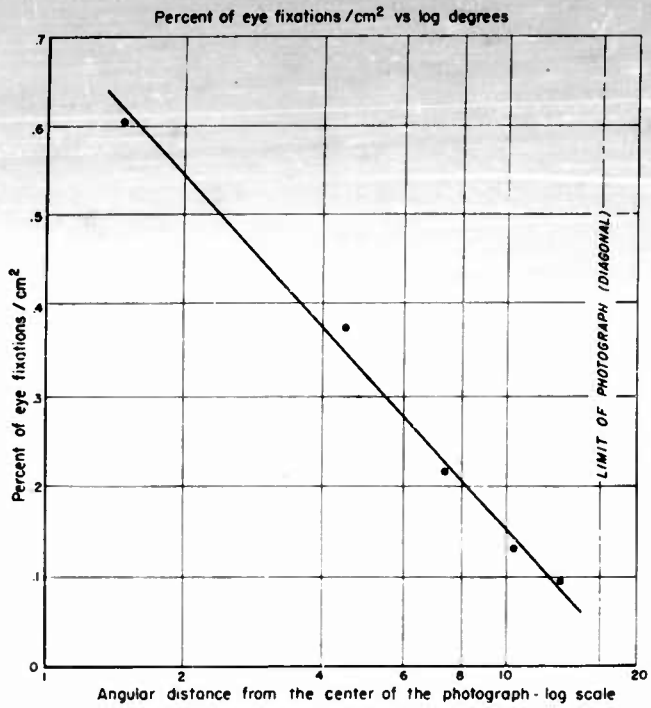

Fig. 2. Analysis of percentage of total eye fixations per cm² as a function of visual angle from the center of the photograph.

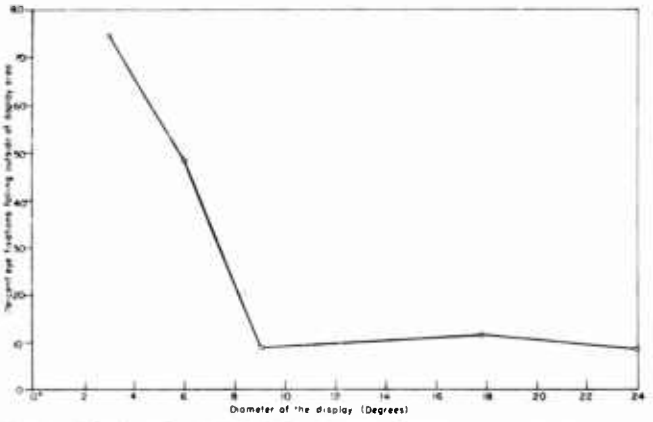

Fig. 3. Percentage of eye fixations not falling in the display area as a function of the visual angle subtended by the display.

display area as a function of display size. The reader will note that there is a sharp break in this function at 9°. Search techniques change markedly for displays below 9° in size, i.e., all functions change radically when the display size falls below this diameter. In connection with this phase of the program, it should be noted that only static displays were employed. Obviously, one many introduce variables which will modify these results.

Based on these results, the optimum size display recommended was 9°. This recommendation was based upon the fact that the larger the display, the greater the non-uniformities in coverage, and the smaller the displays below 9° the less efficient the coverage in terms of the percentage of time spent viewing the display.

Analysing these data from still another point of view, it would seem, that while the general path of search was controlled exclusively by central nervous system processes (here distinguished from foveal, or central retinal control), the individual eye movements executed within the general path of search were largely dominated by effects of peripheral retinal stimulation. Many factors tended to confirm this conclusion. Studying individual records, one finds a surprisingly large percentage of the individual eye fixations falling upon objects in the display which would be expected to act as strong peripheral retinal stimuli. That is, the characteristics of these objects in terms of contrast, size, etc., tend to make them outstanding stimuli. Further, in the studies within this series where degradation of the displays was employed, it was found that the characteristics representing various facets of the individual eye fixations changed markedly. Specifically, this statement is derived from analysis of the data concerning durations of fixation, and interfixation distances. If the individual fixations within the general path of search had been based on a form of random walk, one would not expect the characteristics of the individual fixations to change as markedly, or to be as sensitive to changes in quality and in nature of the display. When degradation was introduced, it was found that the time needed to locate critical objects was markedly increased. In addition, durations of fixation increased, and interfixation distances decreased. This means that if the quality of the display is degraded, one covers less area per unit time in order to obtain considerably less information. Thus, in a search task, it is necessary to consider the payoff very carefully when dealing with degraded material. On the basis of these types of findings, it becomes important to note that in a search task, it is essential to find ways and means of enhancing those factors to which the peripheral retina is most sensitive. That is, the peripheral retina must first detect an object prior to the central retina recognizing it in critical visual tasks. Once detection has been achieved, those factors to which the central retina is most sensitive must be enhanced. Thus, it must be determined whether magnification, or border enhancement, or contrast enhancement, etc., will best meet the needs of the individual tasks. Work on this phase of the problem is being conducted at Ohio State.

Further, because the visibility of cues and clues to the location of critical details is reduced along with the visibility of the critical details themselves, it becomes important to have more uniform coverage of degraded imagery. It is here that automatic scanning devices, whose rate, and coverage per fixation, can

be adjusted to compensate for retinal sensitivity and display quality factors, would be expected to be most useful.

In other phases of the program, studies were introduced dealing with means of testing the performance of an individual during a search task. A rather simple approach has been devised which requires only that the experimenter be able to state that which is good (or desirable) search performance. Good search performance may be based either upon probability statements, or upon the results obtained when a group of individuals judged superior at the task are asked to perform the task. A study was also run dealing with the effect of limiting the amount of time allowed for search, and still another dealt with the effect of viewing oblique photographs. Another investigation dealt specifically with the nature of the instructions given to the photointerpreter. Unfortunately, space does not allow a more complete discussion of these and many other facets of the problem.

In the above discussion, an attempt has been made to present some of the more general findings obtained in this series of studies. These have dealt with the general organization of the search, the distribution of coverage during search tasks, and an attempt has been made to specify levels at which various phases of search are mediated. In future work on this problem, attention will be paid to ways and means of improving coverage during a search task, particularly in the case of degraded imagery. In addition, attention is being paid to means and methods of enhancing search performance. Thus, we hope to further explore this very intriguing subject.

The author wishes to acknowledge the very great assistance given to him in this work by Dr. Glenn Fry and the several authors found in the list of references. In addition he would like to show his appreciation for the work of Lt. Col. Mildred Hindman, Dr. Louis Bresin and Mr. John Cornejo.

(Refer to page 251 for an addendum to the above paper.)

REFERENCES

1. Fry, G. A., and Enoch, J. M. Human aspects of photographic interpretation. Second Interim Technical Report. Columbus, Ohio: Mapping and Charting Res. Lab., Ohio State Univer., 1957.
2. Fry, G. A., and Enoch, J. M. Human aspects of photographic interpretation. Third Interim Technical Report. Columbus, Ohio: Mapping and Charting Res. Lab., Ohio State Univer., 1957.
3. Fry, G. A., and Enoch, J. M. Human aspects of photographic interpretation. Fourth Interim Technical Report. Columbus, Ohio: Mapping and Charting Res. Lab., Ohio State Univer., 1957.
4. Enoch, J. M., and Wild, B. A study of visual search on oblique aerial photographs. A subtask which is part of the Program on Human Aspects of Photographic Interpretation, MCRL T. P. No. (696)-7-260. Columbus, Ohio: Mapping and Charting Res. Lab., Ohio State Univer., 1957.
5. Kalk, M., and Enoch, J. M. An objective test procedure designed to aid in selecting, training, and rating photointerpreters. A subtask which is part of a program

on Human Aspects of Photographic Interpretation, MCRL T.P. No. (696)-11-267. Columbus, Ohio: Mapping and Charting Res. Lab., Ohio State Univer., 1958.

6. Richman, M., Enoch, J. M., and Fry, G. A. The effect of limiting the time allowed for search on Visual search patterns. A subtask which is part of a program on Human Aspects of Photographic Interpretation, MCRL T.P. No. (696)-12-268. Columbus, Ohio: Mapping and Charting Res. Lab., Ohio State Univer., 1958.
7. Townsend, C., Fry, G. A., and Enoch, J. M. The effect of image degradation on visual search: Aerial haze. A subtask which is part of a program on Human Aspects of Photographic Interpretation, MCRL T.P. No. (696)-13-269. Columbus, Ohio: Mapping and Charting Res. Lab., Ohio State Univer., 1958.
8. Enoch, J. M. The effect of visual search of the degree of generality of instructions to the photointerpreter. A subtask which is part of a program on Human Aspects of Photographic Interpretation, MCRL T.P. No. (696)-14-270. Columbus, Ohio: Mapping and Charting Res. Lab., Ohio State Univer., 1958.
9. Enoch, J. M. The effect of the size of the display on visual search. A subtask which is part of a program on Human Aspects of Photographic Interpretation, MCRL T.P. No. (696)-15-279. Columbus, Ohio: Mapping and Charting Res. Lab., Ohio State Univer., 1958.
10. Enoch, J. M. The effect of image degradation on visual search: Blur. A subtask which is part of a program on Human Aspects of Photographic Interpretation, MCRL T.P. No. (696)-16-280. Columbus, Ohio: Mapping and Charting Res. Lab., Ohio State Univer., 1958.
11. Enoch, J. M., Fry, G. A. Visual search for a complex display: A summary report. A subtask which is part of a program on Human Aspects of Photographic Interpretation, MCRL T.P. No. (696)-17-282. Columbus, Ohio: Mapping and Charting Res. Lab., Ohio State Univer., 1958.

AUTOMATIC SCANNING OF AERIAL PHOTOGRAPHS*

CLARK A. TOWNSEND and GLENN A. FRY

Introduction

The type of automatic scanning employed in this study makes use of a circle which subtends three degrees of visual angle and which moves in jumps across a visual display. Each time the circle comes to rest for the pause between jumps the observer pays attention to the objects that fall inside the circle. The jumping circle follows a path which provides complete coverage of the display.

In free search the interpreter is allowed to play his hunches and look where he feels at the moment that he is most likely to find his target. He follows a path which may come close to but pass on by the target several times before a "strike" is made. The chance of making a "strike" within a given time is dependent upon the visibility of the target, the nearness to the target at each "pass," and the number of passes.

From the eye movement record one can determine the number of passes and nearness to the target and give an account of how the time was spent in finding the target.

From information on previous searches by a given individual it might be possible to predict the frequency of the passes that are likely to be made in a new search and how many passes will be required to find the target. But it is probably not possible to predict with any useful accuracy the direction and amount of any given eye movement from the starting point of the given movement and the history of the past ten or twenty previous movements. The fact that the interpreter may at any time decide to play a new hunch or organize his plan of search would make this kind of prediction almost impossible.

Previous studies have shown that allowing a person to search a display in his own manner generally results in a pattern of eye movements which provide a non-uniform coverage of the display. Work in this Laboratory has shown that the center of a display receives a disproportionately large concentration of eye movements, while the upper left quadrant and the corners receive less attention (1, 2, 3). Other studies have pointed out the importance of peripheral vision in the determination of succeeding eye movements(1, 4, 5). In visual displays which are degraded due to low contrast, small size of critical details, blur, etc., the peripheral visibility is greatly reduced. This will obviously serve to lower the detection capabilities of the observer during any given fixation. But degradation not only limits the amount of information available per fixation for a stationary eye, it also limits the extent to which peripheral objects can attract the attention of the eye as it moves from point to point and hence will influence the pattern of eye movements.

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Automatic scanning of displays attempts to achieve two objectives. It provides uniform coverage and it allows the interpreter to concentrate at any moment on a small circumscribed area of the display. If the scanning mechanism is designed to cover all parts of the display and if the photointerpreter is able and willing to follow the instructions for using the mechanism, this should insure a much higher degree of uniformity in coverage of the pictorial material. In degraded displays, the interpreter is not receiving strong peripheral stimulation, and hence a scanning device, which limits the extent of the display under surveillance at any given moment, will make it more nearly coincide with what the observer is able to see and allow him to center his attention upon this area.

Automatic scanning might also lend itself to the procedures used in training photointerpreters. If a given search pattern, for example, a spiral pattern(6), can be determined to be more efficient, then a mechanism could be designed which would present this type of movement to the interpreter. This should have the effect of breaking down whatever search pattern the individual would normally follow and substituting for it a more desirable pattern. After a suitable training period the individual would be expected to follow this particular pattern even when the scanning device was not being used, i.e., under conditions of "free search."

A consideration of the possible types of automatic scanning devices is now in order. Basically there are two techniques to consider in the design of a scanning mechanism. The first is the case where the visual display remains fixed in space and the scanning marker, which the eye must follow, moves across it. The second technique is the case where the scanning marker remains fixed and the display is moved across the field. The first approach has the advantage that it is more nearly like the free search condition in that the eyes are moved by the observer in order to cover the photograph. This would seem to be a more natural condition than one in which the eyes are supposed to remain relatively motionless. The fact that the observer must be more active might be an aid to his attention. The second approach, that of moving the display, is, for example, better suited for incorporating such optical aids as auxilliary magnifiers which may be used at the subject's discretion. The matter of which technique is less fatiguing is also worth considering in the design of such an instrument.

Two factors suggest that, no matter what is to be used as the scanning marker, it should not completely mask off the remainder of the display outside of the fixation area. If masking does occur, the interpreter must view each discretely presented area out of the context of the overall display which will undoubtedly decrease his interpretive ability. Also, any eye movements which are made outside of the exposed area will result in no information being obtained by the subject. It has been shown that as the exposed area is made smaller there is a greater tendency for fixations to occur outside of the exposed area and complete masking would only serve to totally waste these eye movements(3).

The scanning marker itself may be a spot of light (circle, square, etc.) projected onto the display and brighter than the remainder of the display, or it may be merely a projected outline form. In some cases a physical outline form may be

used. In the following study both a projected and an actual outline form were used against an opaque target (photograph) viewed by reflected light.

Apparatus

In order to carry out this study, the instrument shown in Fig. 1 was designed, built, and was used in conjunction with a modified ophthalmograph. It is described in detail in a separate report(7).

The driving mechanism at the extreme left of Fig. 1 was designed so that it would either move a vertical photographic display across the field of view while

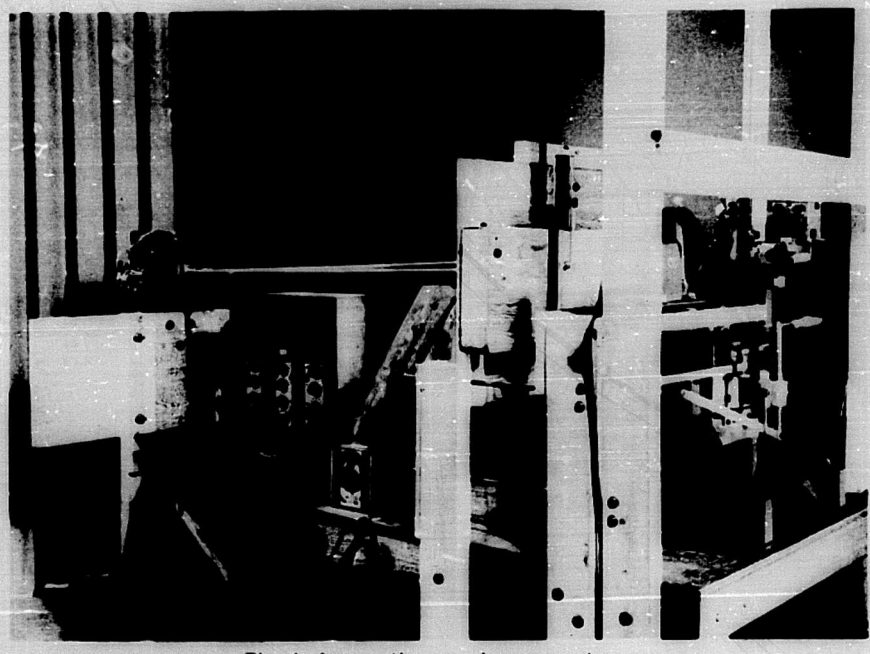

Fig. 1. Automatic scanning apparatus.

the fixation marker remained stationary, or move the marker across a stationary display. The subjects were expected to fixate the center of the marker in either case. The movement produced by the instrument was a series of horizontal jumps and pauses from right to left followed by a single upward jump. In turn this was followed by another series of movements from left to right and then another upward jump. This cycle was repeated five more times to completely cover the display. The extent of the vertical movement was equal to each horizontal movement. A jump lasted one-seventh the duration of a pause. The motion of a jump gradually accelerated and then decelerated so that no violent jar of the instrument occurred. Each horizontal scan was composed of 12 jumps and 12 pauses. There was a total of 12 horizontal scans, resulting in 144 separate pauses to cover

the entire display which was 9 inches square. The maximum rate of this instrument, as used in this study, was 1.5 movements per second although by changing the gearing much higher rates could be obtained.

In order to achieve faster rates of scanning a projected marker was used. A front surface mirror was placed in the path of the beam from the projector. The mirror was moved to make the marker jump. The duration of the jump was less than 0.05 second. The maximum possible rate using this apparatus was five movements per second.

Procedures and Results

Feasibility of Automatic Scanning

In order to test the feasibility of automatic scanning, a series of aerial maps was prepared similar to those used in previous experiments conducted at this Laboratory. Again, a single Landolt "C" was placed on each 9" x 9" map and the subjects were instructed to locate it. Since it appears that any degrading of the display results in essentially the same behavioral changes in eye movements and search patterns(5), contrast was chosen as the attribute to be varied. A series of maps of different contrasts similar to those reported in(4) was prepared. Each map was composed of six shades of gray. By varying the exposure in making the prints the overall contrast was reduced as well as the contrast of the "C" which was placed on a background of intermediate brightness (number 4 on the gray scale in Fig. 2). The reflectance values for the different maps are shown in Fig. 2. The overall contrasts as well as the contrasts of the "Cs" are shown in Table 1. That this procedure simulates aerial haze was demonstrated in the above mentioned report(4).

TABLE 1

CONTRAST SPECIFICATIONS OF THE AERIAL MAPS USED IN THIS STUDY

Map	Overall Contrast	Contrast of "C"
A	95.2%	80.5%
B	72.2	51.0
C	20.0	11.0
D	8.6	6.2
E	2.1	2.0

These maps were placed in a vertical plane, 19.5 inches from the centers of rotation of the eyes, at which distance the "C" subtended an angle of 13'. The illumination was uniform over the map at 115 foot candles. The scanning marker was a one inch (3°) diameter outline circle which covered the entire map in 144 separate jumps; twelve lines of 12 stops each, 2½° between stops. Each fixation of the mechanism lasted for one second. The subjects were told to keep their attention centered in the circle and to respond if and when they became aware of a "C."

In half of the cases a circle was moved over the map and in the other half the map was moved behind the stationary circle. The pattern described by this

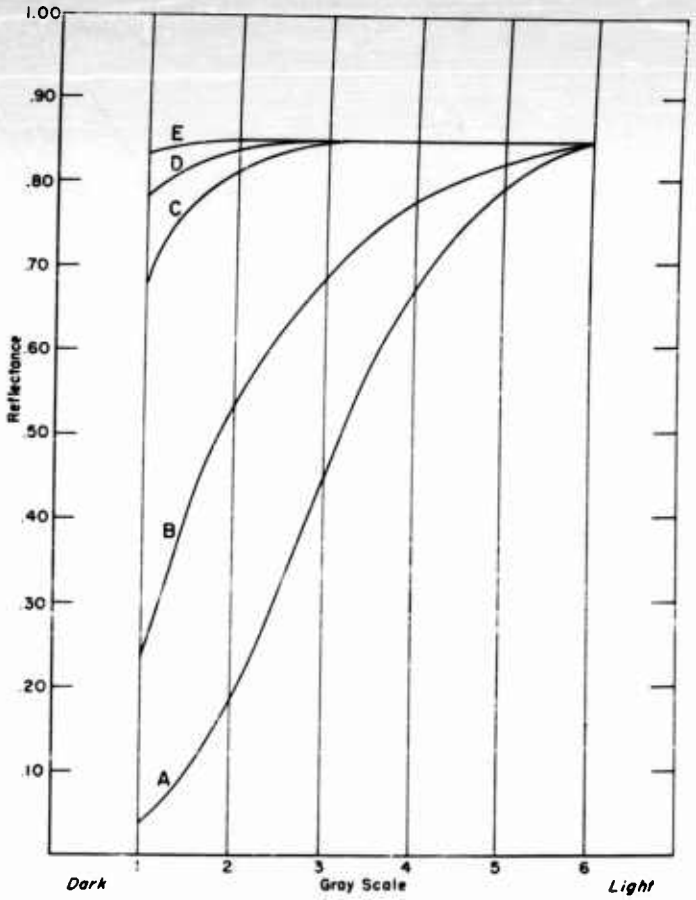

Fig. 2. Reflectance values produced by varying exposure time in making prints of maps.

motion was that of a boustrophedon, i.e., alternate rows of left to right and right to left. In the case of the moving marker it began in the lower right corner and for the moving map in the upper left corner.

Three subjects viewed maps of the five different contrasts previously mentioned. Eye movement recordings were made on the modified ophthalmograph described previously(7).

An instrument was designed and built to automatically transcribe the traces on the film into graphical form. This is illustrated in Fig. 3. The film was projected by an enlarger onto a vertical screen (*A*) with a horizontal line (*B*) drawn on it.

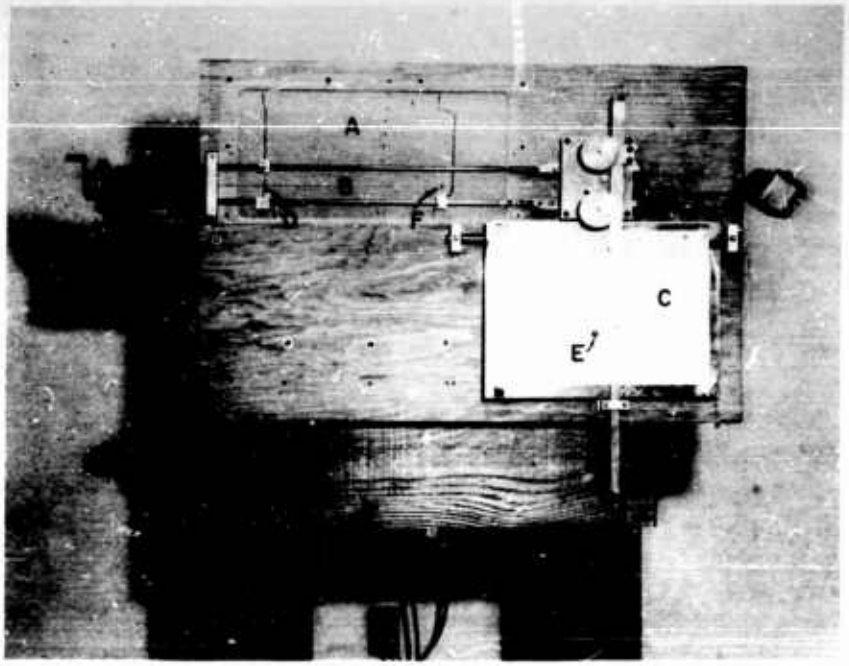

Fig. 3. Instrument for transcribing data from ophthalmograph records.

As the film was fed through the enlarger a vertical table (*C*) was moved synchronously along the horizontal. The table moved at ⅛ the rate of the film. A sheet of graph paper was attached to the table. The motion of a pointer (*D*) which moved horizontally across the screen was translated 90° to a vertical motion across the table. A pencil (*E*) was attached to this vertically moving rod. As the film was fed through, the pointer was lined up with the eye movement trace for each fixation made by the eye. This produced a trace on the graph paper which corresponded to the film trace but with the movements magnified and the time scale reduced. One inch on the paper corresponded to 8″ on the film which, moving through the ophthalmograph at ½″ per second, corresponded to 16 seconds. The horizontal and vertical components of the eye movements were imaged separately on the film which necessitated tracing each component at a time. This technique was used when the display was moved across the fixation marker. Theoretically an almost straight line should result if the subject were behaving according to instructions. A typical result is shown in Fig. 4.

It can be seen that almost all of the fixations are located within the 3° zone, corresponding to the circular fixation marker. The number of times that the trace fell outside of the 3° circle is tabulated for the different contrast levels in Table 2. For two subjects, GL and GB, the number of eye movements outside the 3°

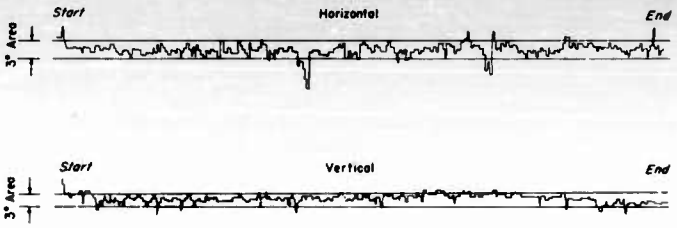

Fig. 4. Typical record of horizontal and vertical components of eye movements resulting from the use of the stationary scanning marker.

TABLE 2

NUMBER OF TIMES THAT THE EYE MOVEMENT TRACE FELL OUTSIDE OF THE 3° ZONE

Over-all contrast of map	Subjects		
	G.L.	C.S.	G.B.
2.1%	22	14	20
8.6	48	12	43
20.0	38	9	34
72.2	34	6	37
95.2	45	9	71

zones is definitely least in the map of lowest contrast. This particular photograph is virtually a sheet of white paper. There are no peripherally visible "determiners of attention" to attract the eye, as there are in the other maps which show a higher number of fixations outside of the 3° area. Subject CS put forth so much effort to keep his eyes centered that his data are probably not comparable. After this series was completed his eyes were tearful and he complained of fatigue.

In order to analyze the records when the circular scanning marker was moved over the photograph, two pointers were moved horizontally across the images of the eye movement traces. The motion of one (*D*) was translated ninety degrees as before and this was used to record the trace of the vertical component. The motion of the vertical table was synchronized with the displacement of the other pointer, (F) which was lined with the trace of the horizontal component. For each eye fixation the two pointers were lined up and a pencil mark was made on the paper attached to the table. By connecting these successive marks, a serial plot of the subject's eye movements was made. Figure 5 is an example of one of these plots. The subjects generally reported that it seemed easier to search when they followed the moving marker rather than keeping their eyes fixed while the display was in motion.

It was apparent from these results that untrained subjects are able to follow instructions, keeping their fixation for the most part within the circle, and thereby

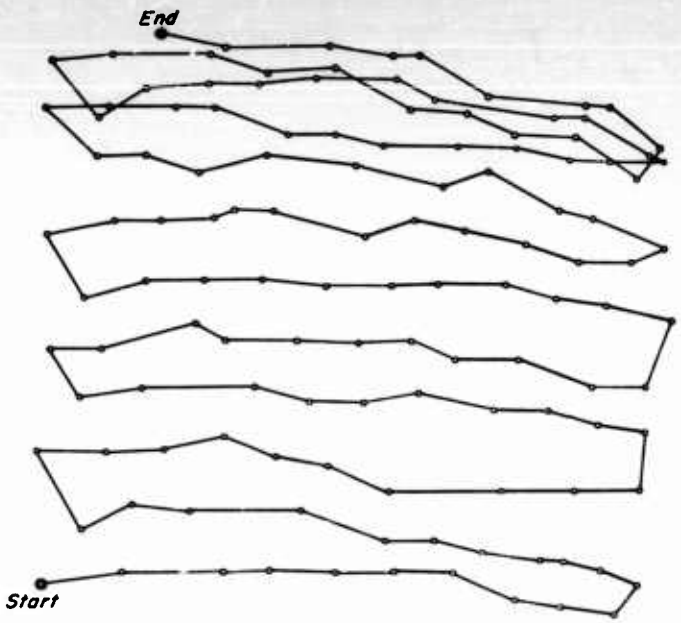

Fig. 5. Typical serial plot of eye movements resulting from the use of the moving scanning marker.

obtain uniform coverage of the display. Every record made with the automatic scanning mechanism showed a more uniform coverage than any record made previously under free search conditions. Practically, this means that if a critical object is located somewhere in the display, the observer will have one certain chance of seeing it with central vision. Assuming a critical object to be located randomly on a large number of displays, and assuming one hundred per cent probability of detection, then on the average, one-half of the time necessary for the automatic scanning device to complete its cycle would be needed for detection.

When the automatic scanning device is operating at a speed of one jump per second, 72 seconds must be the average time necessary to locate a critical target. At high overall contrasts (95.2, 72.2, 20) an average time of less than 20 seconds was necessary to locate the "C" when the subjects were engaged in free search. In order for the automatic scanner to equal this average time it would be necessary to make about 3.5 jumps per second (at the $2\frac{1}{2}°$ jump used in this experiment). This is much faster than the eye can follow, as will be shown below. Therefore, at high contrast levels automatic scanning cannot compete with free search. At low contrast levels the times required for locating the "C" become longer. This is shown in Table 3 which is based on data from a previous study(4).

TABLE 3

NUMBERS OF Ss REQUIRING DIFFERENT TIMES TO LOCATE THE "C"

Time required to locate "C"	Contrast of the "C"				
	47.2%	16.2%	4.0%	3.3%	1.7%
0- 10 sec	16	15	2		
11- 20	2	3	3	3	
21- 40			5	5	
41- 60			3	2	
61- 80			2	2	
81-100					
101-120					
>120			3	6	18

In this previous study 9 in. x 9 in. aerial maps were used the same as in the present studies and contrast was controlled in exactly the same way. The "Cs" subtended 10′ instead of 13′ as in the present study. The subjects were simply presented with the maps and asked to find the "C" using free search. They were given no clue as to the location of the "C."

At the lowest contrast level, two per cent, the "C" was not found by any of the subjects in the 120 seconds allowed and, if at this contrast level the automatic scanning mechanism offers the interpreter a finite chance of seeing the target in one complete cycle, automatic scanning should be used.

If the objective is to find the targ egardless of the amount of time involved, one ought to compare free search and automatic scanning on the simple basis of a chance of finding the target without reference to time. From Table 3 it appears that, when using free search an interpreter does not find the target in 80 seconds, he is not very likely to find it at all. If, therefore, subjects are allowed 120 seconds for free search, one can compare the frequency of successes with the frequency of successes obtained with complete cycles of automatic scanning involving 144 seconds per cycle. This kind of comparison can be made by tabulating the results obtained with automatic scanning in the present study and the results of free search in the previous study(4). The task in each case was the same (locating a single Landolt "C" on a 9 in. x 9 in. aerial map) but the contrasts and sizes of the "Cs" used were not exactly identical. In each case the subjects had no prior knowledge as to the locations of the "Cs." The free-search group was composed of 18 subjects and each was allowed two minutes for each map. The automatic scanning group was composed of three new subjects. Table 4 lists the percentages of correct "C" detections for both free search and automatic scanning at various contrasts.

It appears that for contrasts of the order of 10 per cent and higher, free search is just as efficient and certainly faster than automatic scanning. The target is always found in both cases but less than 20 seconds is needed to find it in free search. At contrast levels of the order of 3 to 6 per cent a larger number fails altogether to find a "C" in the two minutes allowed for free search than in the case of automatic scanning. But when a "C" is found in free search it takes much less than the average time of 72 seconds required for automatic scanning.

TABLE 4

COMPARATIVE PERFORMANCE DATA FOR FREE SEARCH AND AUTOMATIC SCANNING

Free search (Size of "C" = 10′)		Automatic scanning (Size of "C" = 13′)	
Contrast of "C"	"Cs" correctly detected	Contrast of "C"	"Cs" correctly detected
47.2%	100%	80.5%	100%
16.0%	100%	51.0%	100%
4.0%	83%	11.0%	100%
3.3%	67%	6.2%	83%
1.7%	0%	2.0%	17%

At low contrast levels none of the subjects can find the target in the two minutes allowed when free search is used but, when automatic scanning is used, the target is actually found part of the time.

If the objective is to find the target regardless of the amount of time involved, automatic scanning has the advantage over free search for contrasts of the order of six per cent and lower.

Relationship Between Scanning Movements and Eye Movements

For this aspect of the study, the projection scanner was used, and again the fixation-holding device was a 3° diameter circle which jumped 2½° between each fixation. Maps of three contrast levels were used: 95.2, 20.0, and 2.0. The durations of the pauses of the scanner were varied equally among the following times: 0.2, 0.3, 0.4, 0.5, 0.6, and 0.8 seconds with virtually instantaneous movements between pauses. Five subjects were tested in this part of the experiment.

Since the scanner made 12 fixations along each horizontal line, the optimum number of eye fixations should also be twelve. However, for a slow scan, the subjects invariably made more than this and for a fast scan considerably fewer. The average data are given in Table 5 and presented graphically in Fig. 6. From

TABLE 5

AVERAGE NUMBER OF FIXATIONS PER SCAN LINE MADE BY EACH S FOR VARIOUS DURATIONS OF THE SCANNER PAUSE.**

Duration of Scanner Pause	Fixations per Scan Line						Average Duration per Fixation
	J.B.	B.P.	G.L.	L.A.	F.L.	Aver.	
.8 sec	15.5*	14.6	17.1	16.6	16.4	16.0	.600 sec
.6	14.2	13.6	16.6	13.7	15.0	14.6	.493
.5	13.6	13.2	14.0	13.2	12.3	13.3	.451
.4	11.7	10.8	11.8	10.9	12.0	11.4	.421
.3	9.5	10.2	11.2	9.6	9.8	10.1	.356
.2	7.6	8.0	9.1	7.2	6.6	7.7	.312

*Each of these values is based on 12 lines, four for each of the three contrast levels.
**The average duration per fixation is shown.

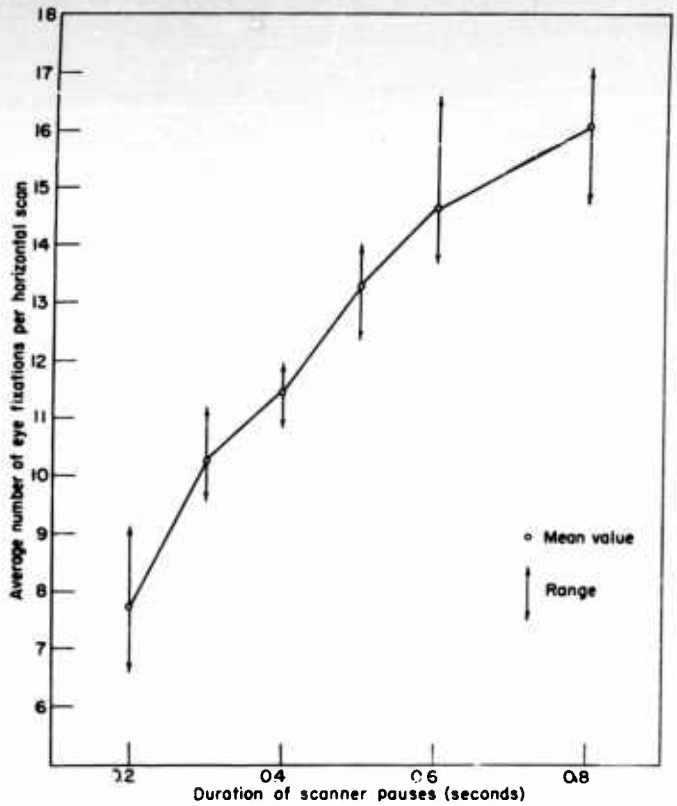

Fig. 6. Relationship between scanner rate and number of eye fixations.

this information the average duration per fixation has been calculated for each rate of the scanning device. These are also given in Table 5. Of interest is the fact that all the subjects tended to group together closely and all showed the same type of changes.

Although varying the rate made a great difference in the number of eye movements per line, varying the contrast had virtually no effect. The data are shown in Table 6. This result was unexpected since, in a previous study, decreasing contrast was shown to increase the average duration per fixation during free search conditions. The automatic scanning mechanism appears to overcome this natural tendency. It was therefore concluded that the optimum duration, as far as synchronizing eye movements with scanning movements, is between 0.4 and 0.5 seconds, i.e., a rate between 2 and $2\frac{1}{2}$ movements per second. However, it will be shown later that this is not necessarily the proper rate for maximum efficiency of detection.

TABLE 6

FIXATIONS PER LINE AS A FUNCTION OF RATE AND CONTRAST
(AVERAGE DATA FOR FIVE SUBJECTS)

Duration of Scanner Pause	Contrast		
	95.2%	20.0%	2.1%
.8 sec	16.4	16.2	16.4
.6	14.6	15.6	14.8
.5	13.7	13.6	13.8
.4	12.2	11.6	11.1
.3	9.6	10.5	10.0
.2	7.6	8.2	7.4

Another method of analysis is presented. The number of times that a subject looked in the direction opposite to the motion of the automatic scanner was very easy to determine from the records. This type of eye movement is called a "regression" when applied to eye movements during the reading process. The same terms will be used here. The average number of regressions per horizontal line for all five subjects are presented in Table 7.

TABLE 7

COMBINED AVERAGE NUMBER OF REGRESSIONS PER HORIZONTAL LINE FOR VARIOUS RATES AND CONTRASTS

Contrast	Duration of Scanner Pause						
	0.8 sec	0.6	0.5	0.4	0.3	0.2	Average
95.2%	3.00	1.00	1.50	0.50	1.00	0.00	1.00
20.0	2.75	1.75	0.50	0.75	0.75	0.00	1.08
2.1	2.25	1.50	1.00	0.00	0.50	0.25	0.92
Average	2.67	1.42	1.00	0.42	0.42	0.08	1.00

Contrast has virtually no effect upon the number of regressions, but the rate of movement has a very marked effect. Both the durations of fixation and the number of regressions seem to be determined solely by the mechanical system which operates the scanner, rather than by the properties of the display itself.

Use of Scanner for Detection Purposes

The final part of this study was undertaken to determine the probability of detecting a Landolt "C" of a given size and contrast during a single scanner pause.

A 9 in. x 9 in. photographic print was made which contained 36 Landolt "Cs," placed randomly in the 144 square areas scanned by an outline form, 0.785 inches (2.33°) square. Each "C" fell in one and only one square. Three contrasts were used: 9, 15, and 28. These were combined with three sizes: 5, 10, and 20 minutes, so that nine combinations of size and contrast were possible. Each combination was reproduced four times on the photograph. By rotating the photograph to four positions a total of 144 "Cs," in varied locations, could be presented to the subjects. The illumination on the photograph was 40 foot candles which

produced a brightness of 34 foot Lamberts for the background upon which the darker "Cs" were placed.

A brief interrupting switch was connected to the light which produced the corneal reflection for the ophthalmograph. Each time the scanner made a jump a break in the eye movement trace could be detected. A light was installed inside the ophthalmograph which could be activated by a push button which the subject controlled. He was instructed to respond by pushing the button each time he detected a "C" inside the square area and this pressure produced a narrow black streak on the film. The number of correct responses as well as any errors could be then read from the ophthalmograph record. The photograph was scanned with both the moving scanner and the moving picture. The duration of each pause was 0.65 second.

As far as correct detections were concerned there was no significant difference between either method of scanning. Therefore the data are combined in Table 8.

TABLE 8

CORRECT DETECTIONS (IN PER CENT) FOR NINE COMBINATIONS OF SIZE AND CONTRAST, COMBINED FROM BOTH TYPES OF SCANNING

Size	Contrast		
	9%	15%	26%
20′	96.4%	99.1	99.1
10′	58.9	92.9	98.2
5′	16.1	70.5	94.6

The total presentations of each combination were 112. There were five subjects, two of whom participated in both methods of scanning. Of interest here is the fact that either enlarging the object size or raising the contrast will increase the chances that an object will be detected.

Since almost all of the combinations of size and contrast resulted in high percentages of detection, it was necessary to treat the data in the following manner in order to extrapolate to lower percentages of detection. The data have been plotted, as shown in Fig. 7, and fitted with smooth curves which, for values of P below 70 per cent, have the same form as the equation for the integral of the normal curve:

$$P = 50 + \frac{100}{\sigma\sqrt{2\pi}} \int_{\bar{x}}^{x} e^{-0.5(x-\bar{x})^2/\sigma^2}\, dx \qquad (1)$$

where P = per cent detection,

x = log per cent contrast, and

$\bar{x}$ = per cent contrast at which P = 50, and $\sigma = 0.149$.

It is obvious that a curve having a specific slope is required to fit the data for five minute "Cs." Curves having the same slope have also been used to fit the data for 10 and 20 minute "Cs." Assuming that the threshold corresponds to the

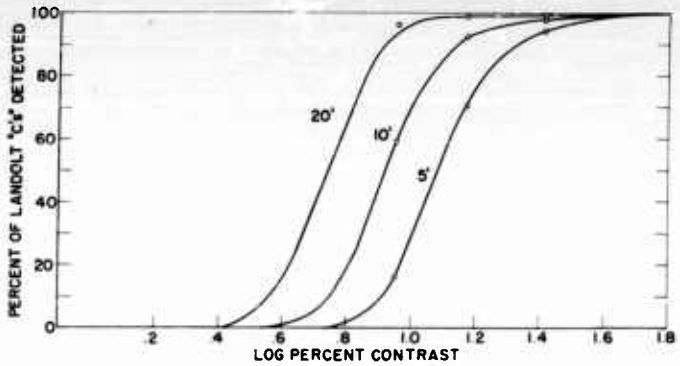

Fig. 7. Per cent of Landolt "C's" detected as a function of contrast for three sizes.

50 per cent level of detection, contrast thresholds can be determined from Fig. 7, and can be plotted as a function of size as shown in Fig. 8. At the threshold level,

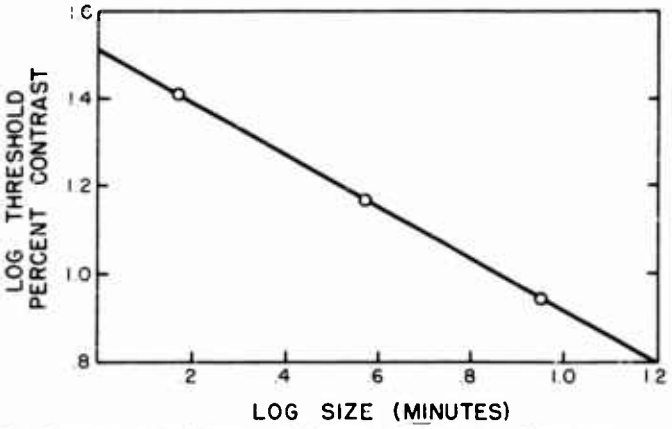

Fig. 8. Contrast threshold for detecting presence of a Landolt "C" as a function of the outside diameter of the "C."

log per cent contrast (x) proportionately increases as log size (y) decreases, i.e.,

$$x = -.595y + 1.524. \tag{2}$$

The data shown in Fig. 7 were replotted in Fig. 9 showing per cent detection as a function of log size for three different contrast levels. The data are fitted by smooth curves which, for values of P below 70 per cent, conform to the following equation:

$$P = 50 + \frac{100}{\sigma\sqrt{2\pi}} \int_{y}^{\infty} e^{-0.5(y-\bar{y})^2/\sigma^2}\, dy \tag{3}$$

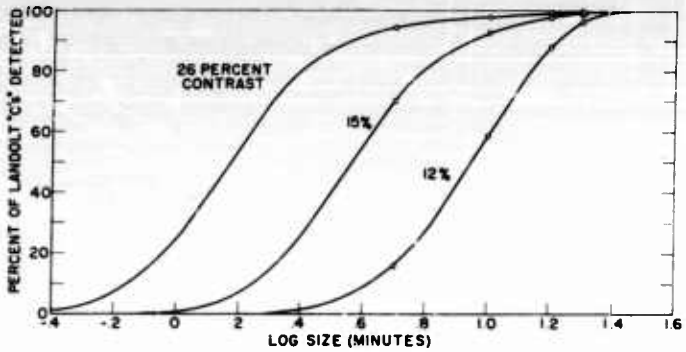

Fig. 9. Per cent of Landolt "Cs" detected as a function of size for three contrast levels.

where y = log size in minutes,

$\bar{y}$ = log size at which P = 50, and $\sigma = 0.251$.

This equation can be derived mathematically from Equations (1) and (2).

Connor and Ganoung(9) have also obtained data for frequency of seeing, using Landolt "Cs" of different size and contrast. When they plotted frequency of seeing against log size they found that curves for different contrast levels all have about the same slope. This confirms what has been assumed to be the case in Fig. 9. Fry and Enoch(10) have also investigated frequency of seeing of Landolt "Cs" using different combinations of contrast and size. They found that the slope increases as the size increases in the range from 0 to 25 minutes diameter. Contrary to these findings by Fry and Enoch, the curves in Fig. 7 all have the same slope.

Although both scanning methods yielded approximately the same proportions of correct responses, there were two differences worth noting. There appeared to be a greater tendency to make errors (responding to a "C" when none was present) under the conditions when the photograph moved behind the stationary fixation device. The two subjects, who viewed the photograph under both conditions, showed this characteristic: Subject EK, 0 against 4 errors; Subject FL, 5 errors against 26. All subjects who viewed the moving photograph, including several from whom no data were recorded, reported dislike for this method, claiming it was too tiring and that it required so much effort to keep the eyes fixed that they sometimes "forgot" the task of detection.

Three of the five subjects also viewed the photograph in two positions with the duration of each pause increased to one second. "Cs" of each contrast level were presented a total of 72 times (24 for each size) and "Cs" of each size a similar number of times. That slowing the rate of the scanner does serve to increase detection is evident for the smaller sizes and the lower contrast levels, shown in Table 9. However, as correct detection improves, the number of errors made also

TABLE 9

NUMBER OF CORRECT DETECTIONS FOR A TOTAL OF 72 PRESENTATIONS AT EACH CONTRAST AND SIZE

Contrast	Fast scan (0.65 sec)	Slow scan (1.00 sec)
9%	41	44
15%	60	69
26%	71	71
Size		
5′	39	50
10′	61	64
20′	72	70

increases. The subjects' errors are as follows, the first numbers are the errors for the fast scan (0.65 seconds) and the second are for the slow scan (1.0 second): Subject EK, 0 against 4; FL, 2 against 3; LA, 2 against 7.

It can be reasonably concluded that the errors were made in response to what the subjects believed to be "Cs" of low contrast and small size. These were probably due to small dust particles which had settled on the photograph, even though care was taken in this handling. This serves to show how important it is to process and handle photographs which may contain critical objects near the threshold of detection.

During this study, eye movements were recorded while the subjects who had previously used the automatic scanner were engaged in free search. Both followed essentially the pattern of the scanner. One subject was totally unaware of this until he was shown the results while the other claimed he had consciously attempted to search in this manner. Although the aspect of using the scanner as a training technique was not investigated, these results indicate that there is a potential use of the instrument in this area.

Conclusions

Based upon the results reported above the following tentative conclusions may be reached.

1. Automatic scanning devices are feasible. Subjects are able to follow instructions for their use as shown by ophthalmographic records.

2. Automatic scanning results in a more uniform coverage of the photograph than allowing the subject to move his eyes freely wherever he desires.

3. The fixation-holding device moving over the display seemed to be easier for the subjects to use than the stationary device with the moving display and appeared to give rise to fewer errors.

4. Free search is more efficient for detection purposes when the objects to be sought have high visibility. For low visibility targets the automatic scanning device is to be preferred. Further experimentation is needed to determine precisely where the change in scanning procedures should be made. This will depend not only upon the physical characteristics of the display (size, contrast, blur, etc.) but also upon the time allowed for search, and the type of object being sought.

5. Eye movements made when using an automatic scanner are governed by the characteristics (size, rate, jump, etc.) of the scanning device itself rather than by the characteristics of the display. This is important since the display has a very marked influence upon eye movements during free search.

6. The scanning rate at which the number of eye movements correspond to the number of scanner movements is not necessarily the optimum rate for most efficient detection. The rate should be somewhat slower than this value to achieve the maximum level of detection.

7. When searching for objects of low visibility, it is important to keep the display free from artifacts due to processing and handling, which might be mistaken for a target.

REFERENCES

1. Fry, G. A., and Enoch, J. M. Human aspects of photographic interpretation. Fourth Interim Technical Report. Columbus, Ohio: Mapping and Charting Res. Lab., Ohio State Univer., 1957. (Contract No. AF 30(602)-1580.)
2. Enoch, J. M. The effect on visual search of the degree of generality of instructions to the photointerpreter. A subtask which is part of a program on Human Aspects of Photographic Interpretation, T.P. No. (696)0140270. Columbus, Ohio: Mapping and Charting Res. Lab., Ohio State Univer., 1958. (Contract No. AF 30(602)-1580.) 30(602)-1580.)
3. Enoch, J. M. The effect of the size of the display on visual search. A subtask which is part of a program on Human Aspects of Photographic Interpretation, MCRL T.P. No. (696)-15-279. Columbus, Ohio: Mapping and Charting Res. Lab., Ohio State Univer., 1958. (Contract No. AF 30(602)-1580.)
4. Townsend, C., Fry, G. A., and Enoch, J. M. The effect of image degradation on visual search: Aerial haze. A subtask which is part of a program on Human Aspects of Photographic Interpretation, MCRL T.P. No. (696)-13-269. Columbus, Ohio: Mapping and Charting Res. Lab., Ohio State Univer., 1958. (Contract No. AF 30(602)-1580.)
5. Enoch, J. M. The effect of image degradation on visual search: Blur. A subtask which is part of a program on Human Aspects of Photographic Interpretation, MCRL T.P. No. (696)-16-280. Columbus, Ohio: Mapping and Charting Res. Lab., Ohio State Univer., 1958. (Contract No. AF 30(602)-1580.)
6. Fry, G. A., and Enoch, J. M. Human Aspects of Photographic Interpretations. Addenda to Sixth Interim Technical Report, MCRL T.P. No. (696)-9-265, Columbus, Ohio: Mapping and Charting Res. Lab., Ohio State Univer., 1957. (Contract No. AF 30(602)-1580.)
7. Fry, G. A., and Townsend, C. A. Automatic scanning devices for visual inspection of Aerial Photographs. (In preparation.)
8. Fry, G. A., and Enoch, J. M. Human aspects of photographic interpretation. Second Interim Technical Report. Columbus, Ohio: Mapping and Charting Res. Lab., Ohio State Univer., 1957. (Contract No. AF 30(602)-1580.)
9. Connor, J. R., and Ganoung, R. E. Experimental determination of the visual thresholds at low values of illumination. *J. Opt. Soc. Amer.*, September, 1935.
10. Fry, G. A., and Enoch, J. M. Visual perception of the orientation of a Landolt ring. MCRL T.P. No. (696)-18-292. Columbus, Ohio: Mapping and Charting Res. Lab., Ohio State Univer., 1959. (Contract No. AF 30(602)-1580.)

FIELD AND SIMULATOR STUDIES OF AIR-TO-GROUND VISIBILITY DISTANCES*

H. RICHARD BLACKWELL, JAMES G. OHMART, and E. RAE HARCUM

Introduction and Summary

In the past, some investigators have attempted to compute visibility distances for military targets viewed against terrain backgrounds from existing visual detection data obtained with simple targets of uniform luminance presented in the laboratory against backgrounds of uniform luminance. This procedure seems hardly justifiable, unless only relative visibility distances are of interest. The present experiments were carried out to provide information on visibility distances for military targets viewed against terrain backgrounds from the air, utilizing more realistic techniques of measurement.

A coordinated program of field tests and simulator measurements has been made, in which visual detection and recognition ranges for ground targets viewed from aircraft were obtained. Flight speed was fixed at 130 knots. Flight altitude was varied between 2,000 and 7,500 feet. Flight attitude with respect to the position of the sun was varied between 3 and 177 degrees. The target was a vehicular complex consisting of a jeep, a ¼ ton panel truck, and a 2½ ton stake truck. Nine pilot-observers were used, all of whom were commissioned officers of the U. S. Navy and Marine Corps on active duty. The flight tests were made in an SNB-5P aircraft, operating from the Grosse Isle Naval Air Station. The simulator measurements were made in a terrain model facility at the University of Michigan. In all, 109 flight passes were made in the field test program, and 840 passes were made in the simulator program.

Analysis of the data revealed important similarities and differences between the results obtained in the field and in the simulator. The combined sets of data were used to construct probability curves for target recognition as a function of slant range in the field. The curves represent vehicular targets painted battleship gray, viewed against roadway backgrounds. Curves are available for five individual flight attitudes at each of four individual flight altitudes. Data are presented which allow predictions of detection ranges to be made as well.

Procedures and Apparatus

Flight Tests. A standard SNB-5P aircraft was utilized for all flights, made available to Grosse Isle N.A.S. by the Glenview N.A.S. All service and normal flight support was provided by Grosse Isle N.A.S. Without the excellent cooperation of these two Naval Air Stations, the flight test program could not have been completed.

All flights were made at 130 knots indicated air speed. No attempt was made to correct for winds aloft, since a flight pattern was used which equalized the use

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of the four major compass directions during each series of four flights over the target. All altitudes were read from the aircraft altimeter, then corrected to give true height above the terrain. The pilot and co-pilot seats were used equally as observation stations in an effort to average out any peculiarities of flight pattern or windshield distortions.

The terrain site used was a site within Kensington Park near Ann Arbor, Michigan. The park had houses, barns, sheds, and such terrain features as trees, grass and planted fields in average numbers. It also had a variety of road surfaces, including new concrete, new asphalt, quite old asphalt, and gravel. The park was located midway between two major airports (Willow Run and Wayne Major) so that all flights were made in the control zone established between these two. This meant that the observer had to make all the normal flight observations in addition to searching for targets. This feature of the test added realism to the tests, since pilots under military conditions must be concerned about other aircraft as well as targets on the ground.

The target consisted of a ¼ ton jeep with canvas top up, a ½ ton Chevrolet panel pickup truck, and a 2½ ton GMC stake truck with racks on the sides but without a tailgate. The vehicles were all painted with standard Navy battleship gray paint, and were in moderately used condition as far as fading and dust were concerned. The convoy always consisted of all three vehicles parked on the right-hand edge of the roadway, with approximately 2 to 3 vehicles lengths between each two vehicles. The relative positions of the three vehicles were varied randomly among flight passes. The convoy was placed in each of ten target positions on different flights, with the convoy headed in each direction equally often.

Ten target positions were used in all, selected at various points within the target area (which measured 1 nautical mile on a side) to give the pilot-observers a clear view of each target unobstructed by either terrain or vegetation. However, the target positions varied from very easy ones, in which the targets were essentially placed in the middle of a field with little or no vegetation around them, to more difficult ones, in which there were houses and vegetation in the area immediately surrounding the convoy. The ten positions were selected to give approximately equal numbers of East-West and North-South orientations of the convoy. Thus, the observers were equally likely to see the target convoy placed parallel with, or perpendicular to the line of flight.

On each series of flights, the pilot followed a standard cloverleaf pattern, always beginning at the same starting position. The pilot made a N-S pass over the target area and attempted to make a target interception. Whether he succeeded or not, he continued on the cloverleaf pattern and next made a E-W pass. The target was moved to a new position before the E-W pass was made. The flight pattern continued in this way until four passes were made. Since the cloverleaf pattern extended over a square approximately six miles on a side, there was usually sufficient time for the convoy to be moved. In the event that the convoy was not in place when the pilot came to the beginning of a pass path, he was instructed to make a 360 degree turn so as to delay his pass over the target area. All flights were made under conditions of essentially clear air, with the meteoro-

logical visibility equal to 15 miles or more. Scattered clouds were present on some flights. All flights were made between the hours of 1400 and 1700. These hours were selected so that the sun's elevation varied only between the limits of 33 and 57 degrees, with an average value of 45 degrees. The sun's azimuth from true north varied from 244 to 290 degrees, with an average value of 267 degrees.

Before each series of flights, the pilot made several low-level passes over the convoy from each direction so as to familiarize himself with the general appearance of the target. The aircraft then flew off to a position well beyond the limiting visibility range and the convoy was moved to the first target position. After the convoy was stopped in position on the edge of the roadway, the aircraft was directed by two-way radio to begin the cloverleaf pattern.

It was intended that the pilot would use both a detection and a recognition criterion. Detection was defined by the pilot having sufficient information to alter his normal flight pattern in order to verify the existence of a target better. Recognition was defined by the pilot having located the target correctly, and being willing to state the order in which the vehicles were positioned. (It is to be emphasized that the pilot did not have to be entirely correct in identification of the location of the vehicles in the convoy, but he had to be substantially correct.) Because of the flight control needed at the moment of detection, use of the double criterion proved to be impracticable in practice, and so the pilot only indicated the moment of recognition of the target's location and the order of its components.

When the pilot believed he had detected the target, he would verbalize the information he had such as "I think I see you in the Southwest corner heading North, with the jeep first, the 2½ ton truck second, and the panel truck last." If the identification was approximately correct, the pilot was given credit for an interception at the slant range then separating him from the target. If the pilot made essential errors in his identification of the target location, or the order of the vehicles in the convoy, the pass was scored as a miss. The target locations were sufficiently separated so that it was always quite clear whether or not the pilot had correctly located the position occupied by the convoy. The pilot was required to identify correctly the positions within the convoy occupied by the panel truck and the stake truck. These vehicles were usually correctly located whereas the jeep was not always seen.

The slant range at which detection was made was determined in two separate ways. In one method, the pilot photographed the ground immediately under his aircraft at the moment he believed he had recognized the target. In the second, a ground observer tracked the aircraft through a transit, stopping the tracking procedure when the pilot gave his recognition of the target.

The aircraft camera was a standard K-17 aerial camera, belly-mounted. It could be triggered by either the pilot or co-pilot by means of a "pickle switch." The aircraft was put into flight trim and the camera was carefully leveled. Thus, a photograph of the ground could be used to establish the ground coordinates of the aircraft position at the moment the photograph was taken. Subsequently, the

point in the center of each photograph was located on a master photo-mosaic of the test site, and the ground separation between the target position and the aircraft position established. The slant range is readily computed from the known flight altitude.

The ground method was based upon continuous tracking of the aircraft through the telescope of a standard high quality surveyor's transit, located at the target site. When the pilot correctly identified the target, tracking was stopped and the transit elevation was read. In this case, the slant range may be computed from the elevation angle of the transit and the known flight altitude.

It is apparent that the two methods used to determine slant range are only approximate, but they do involve different sources of error. Thus, average values of slant range derived from the two methods should not be subject to systematic bias. For those cases in which both measurements were made successfully, there was no significant difference between the two methods. The average difference between the two measurements amounted to 13 per cent. It was felt that the average values derived from the two methods had reasonable precision.

The nine pilots participating in the tests were all Navy pilots on active duty, temporarily assigned to the University as students. All had the rank of Lt. or higher. The pilots were highly motivated and most conscientious in carrying out the specified flight routine and in reporting target interceptions.

In all, there were 109 flight passes.

Simulator Measurements. The apparatus used in these experiments consisted of a scale model of the selected terrain, scale models of target vehicles and non-target vehicles, a simulated sun, and an observation platform which could be mounted at several heights above a dolly which traveled along a track. The terrain model was a replica at a scale of 1:600 of the terrain over which the field tests were flown. Since the ground area measured approximately 1 nautical mile on a side, the model measured approximately 10 feet on a side. In simulating the actual terrain of the field test, every effort was made to produce exact correspondence of terrain and model. Aerial photographs and contour maps were used to reproduce both the topography and detail of the field. Also, the craftsmen and artists made direct visual inspection of the terrain to be duplicated. The detail built into the model included duplicates of all dirt, asphalt, and concrete roads.

Models of the three vehicles in the target complex used in the field test were constructed at the scale of 1:600. These vehicles were painted a battleship gray which was a visual match to the paint on the actual vehicles. In addition to the target vehicles, non-target automobiles were constructed at the same scale and painted various colors to simulate the paint of civilian automobiles.

The simulation of the sun was provided by a 5000 watt incandescent lamp mounted slightly inside the focal length of a 60-inch reflector. The reflected light rays diverged just enough to cover all four corners of the model. The simulated sunlight was provided both by the direct light rays from the source falling upon the model and by the re-directed light rays from the reflector.

The sky light illumination was provided by two sources, overhead incandescent lights ordinarily used to illuminate the room, and the multiple reflection of these lights and those rays from the sun-simulator which did not fall on the model, from the white walls and ceiling of the experimental room. The outside windows of the room were blackened out. The sky-light illumination on the model measured at 13 different positions over the surface of the model was relatively constant. Illumination values with the sun rays excluded ranged from 23 to 28 lumens/ft^2. The illumination on the model from the sun varied as a function of the distance from the model area to the lamp. The ratio of sun illumination to sky-light illumination was 10:1 at the corner of the model nearest the sun, 4:1 diagonally across the center of the model from corner to corner perpendicular to the sun and 2:1 at the corner of the model farthest away from the sun. However, at about the center of the model this ratio was only about 3:1 because of a slight shadow cast by the light bulb and its supporting arm in the sun simulator. This shadow did not cover any target positions used in the experiment.

An observation platform could be mounted at four heights above a dolly which moved along a track, to simulate heights of 2000, 4000, 5700, and 7500 feet.

The observation dolly was moved by a chain and sprocket attached to a motor which produced a maximum simulated speed for the observation platform of 134 knots. This motor could be controlled from the dolly by the observer or by the experimenter. Next to the observer's chair there were two switches controlling two response-indicator lights. The response lights were located next to a poin' which was attached to the dolly, directly over a numbered tape on the flo Marked at three-inch intervals, the numbered tape extended from the front edge of the model along the entire length of the dolly track.

Ten locations of the target complex were used, which were essentially identical to those used in the field experiments. Of the 10 target positions, two appeared on dirt roads, two fell on the concrete main highway, and the rest were asphalt locations.

In a run of 20 observations, a target complex appeared twice at each of the 10 target positions. In the two appearances of the target at a given location, the direction in which the vehicles were pointed was once one way and once the opposite way. The sequence in which the target vehicles were placed varied from observation to observation according to no set pattern.

The reflector behind the sun-simulating lamp was always tilted about 45° downward and was directed toward the center of the model. The tower supporting the sun could be moved about the model. For a single session for one observer the sun appeared at three azimuths from true north. These azimuths were 58°, 148°, and 238°. The sequence of testing sun azimuths in a given daily session was haphazard, except that an attempt was made to equate the number of times a given sun position appeared in a given order.

The sun remained at a given azimuth for a run of 20 observations in which each target location and convoy heading appeared once.

In a single session only one simulated altitude of the observer was used. The altitude employed for a given observer was chosen primarily to provide the most direct comparison with the field test data for the same observer. For those observers who served for more than one session, different sequences for presentation of altitudes were used.

Before the simulated flight toward the terrain, the observation dolly was moved sufficiently far down the track away from the model so that there was no likelihood that the targets were inside the detectability range for that observer and experimental condition. This distance was also far enough to allow the observer to scan the complete model before the target was seen. When the observer detected what he thought was a target with sufficient certainty that he would have to alter his flight path in an airplane to investigate it more closely, he threw a switch to one of the lights mounted next to the pointer over the markers on the floor. The experimenter recorded the scale reading. This distance to the target, when converted into slant range between observer and target, was called the detection threshold. Whenever the observer changed his mind about the possible target at which he was looking (i.e., he decided that it was not a target after all), then he turned the light off. Later when he detected another possible target, he again turned that light on. The light remained on until the recognition threshold was reached.

When the observer felt that he could report the correct sequence in which the three target vehicles appeared, he threw a second switch which turned on another light by the pointer. This was recorded and later converted into slant range for the recognition threshold. When this recognition was achieved, the observation trolley was stopped, and returned to the opposite end of the track. Although the observer was required to report the target vehicle sequence, this report of sequence was not required to be correct. If the sequence was incorrect the experimenter quizzed the observer about where he saw the target, in order to be sure the observer was actually looking at the target complex. On rare occasions in which the observer was not regarding the target when he reported a recognition, a false positive was recorded, and the observation was dropped from further data analysis.

Sometimes, the observer felt he could report the sequence of vehicles as soon as he could detect them. In this case he threw both the detection and recognition switches simultaneously.

If the observer had failed to detect the targets by the time the micro-switches at the forward end of the track were activated, then the target was considered not seen and preparations were made for the next observation.

An experimental session usually lasted between 3½ and 4 hours. Rest pauses were taken between blocks of 20 observations while the sun's position was being changed.

A green curtain of simulated grass was draped behind the model to provide a background for the model other than the wall of the room which was disturbing to the observers, particularly in simulated low altitude flights.

A total of 840 simulator passes was made in all.

Results

The Raw Data. The first analysis to be reported here involved tallying all the field test data to provide a cumulative probability curve for correct recognition of the target. For comparison, a similar tally was made of all the recognition data obtained in the simulator. The data are presented in Fig. 1. If all that were required were an estimate of slant recognition ranges representing an average of all the altitudes and the flight angles tested, then the probability curve obtained in the field tests would suffice to report the present studies. The probability values plotted in Fig. 1 are presented in Table 1 for convenience It is apparent that the target was recognized correctly only 54% of the time during field tests and only 89% of the time during simulator tests regardless of how short the slant range became. (In the field tests, the aircraft flew on past the target, whereas in the simulator tests, the "aircraft" was stopped just short of the near edge of the terrain model.)

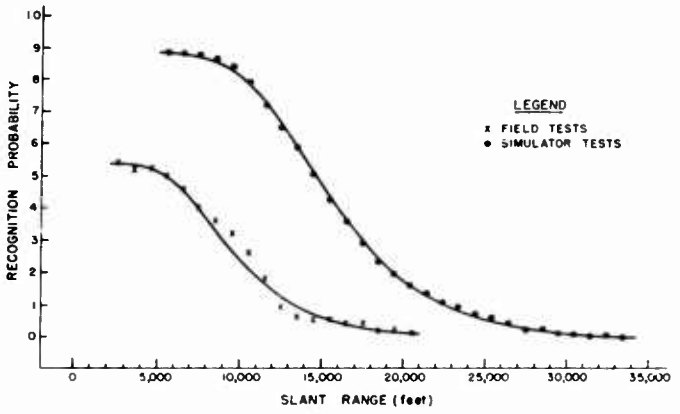

Fig. 1.

It is apparent from Fig. 1 that the simulator did not in fact simulate the conditions of the flight tests, since the results differ to such an appreciable extent. In evaluating the difference obtained, it must be noted that since the complexity of the terrain and target configurations was presumably simulated, we must look for other differences. It is true that there was no atmosphere present in the simulator, whereas the atmosphere present in the field tests reduced target contrast to some extent. However, since the slant ranges were considerably less than 50 per cent of the minimum meteorological visibility, it is unlikely that the presence or absence of the atmosphere was very significant.

There are a host of factors related to the task of flying the aircraft which were not simulated. For example, the pilots had to devote considerable time which might have been spent searching for the target watching the flight controls, listening to radio instructions, etc. There was the vibration and turbulence of the aircraft, and the optical imperfections and distortions of the windscreen. Unques-

TABLE 1

RECOGNITION PROBABILITY AS A FUNCTION OF SLANT RANGE: ALL ALTITUDES AND ATTITUDES COMBINED

Slant Range (feet)	Field Data	Simulation Data
2,500	.54	.89
3,500	.52	.89
4,500	.52	.89
5,500	.50	.89
6,500	.46	.88
7,500	.40	.88
8,500	.36	.87
9,500	.32	.84
10,500	.26	.80
11,500	.18	.73
12,500	.09	.65
13,500	.06	.59
14,500	.05	.51
15,500	.05	.43
16,500	.04	.36
17,500	.04	.29
18,500	.02	.24
19,500	.02	.20
20,500	.01	.16
21,500	.00	.14
22,500	.00	.11
23,500	.00	.10
24,500	.00	.07
25,500	.00	.06
26,500	.00	.04
27,500	.00	.03
28,500	.00	.03
29,500	.00	.02
30,500	.00	.01
31,500	.00	.01
32,500	.00	.01
33,500	.00	.00

tionably, these factors contributed greatly to the difference between field and simulator data.

In commenting upon the field tests and simulator measurements, the pilots emphasized that the cockpit configuration of the aircraft made forward viewing virtually impractical and that field observations had to be made therefore from the side to a point nearly forward. Furthermore, visibility was very poor on the side opposite from the seat occupied by the pilot-observer. Of course, visibility was unlimited in the simulator.

Analyses of Internal Relations in the Simulator Data. An effort has been made to utilize the simulator data to extend the usefulness of the field test data. It was considered desirable that recognition probability data be available under field test conditions for different flight altitudes and attitudes with respect to the sun's position. Sufficient simulator data existed to produce the desired probability

curves. Thus a way was sought to use the *relative* slant ranges obtained under these different conditions in the simulator to correct the average slant range data obtained in the flight tests, under all conditions. It was felt that such a procedure would be reasonably justified if it could be shown that the same relative differences in average data were present in both the field test and the simulator data. The average slant ranges obtained in the flight tests and in the simulator were analyzed to investigate this point.

Figure 2 contains relative slant ranges as a function of flight altitude, for both the field and the simulator data. The data from the two experiments agree well in

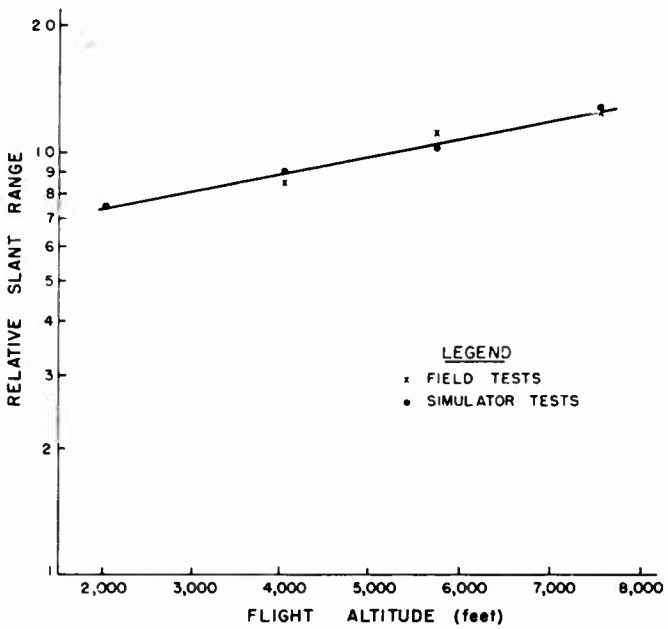

Fig. 2.

defining a systematic change in slant range with altitude. Similarly, Fig. 3 contains relative slant range data as a function of θ, the angle between the line of flight and the sun's position. There is reasonably good agreement between the field test and simulator data in defining a functional relation between these variables. These analyses apparently justify use of internal differences found in the simulator data to apply to the average data obtained in the flight tests so as to produce estimates of the field test data to be expected at different individual flight altitudes and attitudes.

It is also necessary to take account of possible differences in the average recognition probabilities obtained in the simulator data under different flight conditions, and to apply these relative differences to the average probability data obtained in the field tests. In order to make such an analysis possible, it was first

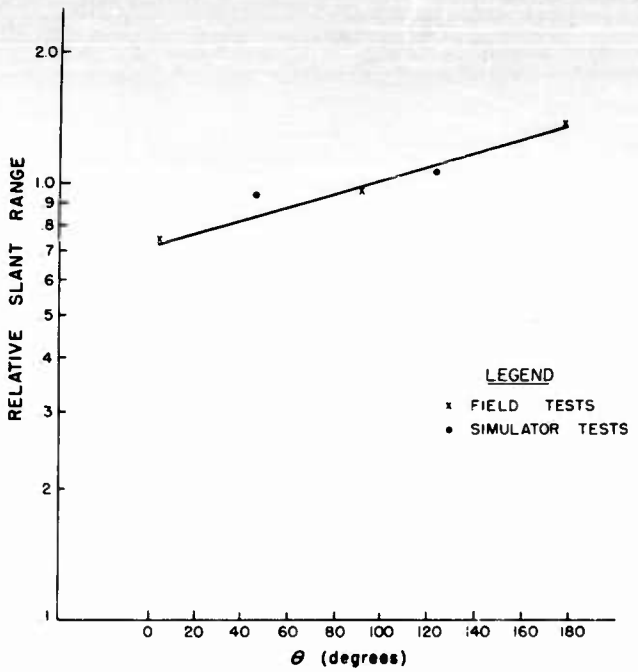

Fig. 3.

assumed that any recognition probability data obtained in our studies represent two statistically separate processes, one of which depends upon the value of slant range and one of which is independent of the value of slant range. The first of these processes is sensory, since the target would be expected to have higher probability of recognition the shorter the slant range. The second process may be conceptualized in terms of a lack of attention, or distraction, or any process which will make it impossible on a given pass for the observer to recognize the target, no matter how short the slant range. It is obvious that such a process must be at work in the data since the recognition probability does not reach unity for values of slant range equal to zero. It is hypothesized here that this process is statistically independent of the first process. Under these circumstances

$$P' = \frac{P}{\varphi}$$

where P' is the recognition probability in the absence of the second process;

P is the recognition probability actually obtained; and

φ is the upper asymptotic value of P.

This equation may be used to correct out the effect of the hypothetical second process for each obtained value of P. Once corrected, the values of P′ may turn out to be more quantitatively described than the raw values of P, containing as they did the two separable processes.

The field test data were corrected for the role of the hypothetical second process, utilizing $\varphi = .54$. The simulator data were likewise corrected, utilizing $\varphi = .89$. The resulting values of P′ were plotted in various ways to see if an analytical expression could be found to describe them. It was found that both sets of data were adequately described by a normal ogive when the values of P′ were plotted against the logarithm of the slant range. The ogive has two parameters, corresponding to the median value of the slant range, and the standard deviation of the frequency distribution from which the ogive may be derived. These parameters are expressed in terms of a logarithmic scale of slant range. According to this theoretical analysis, the proper description of the field and simulator data is in terms of three parameters, median log slant range, σ, and φ.

To verify the adequacy of this analytic treatment of the data, we may construct theoretical probability curves with the three parameters selected, and ascertain to what extent these theoretical curves do indeed fit the data. From the values of median and σ, we define values of log slant range corresponding to various values of P′, utilizing standard tables of the ogive function. We obtain values of slant range for each value of P′. Finally, we obtain values of P from the relation

$$P = P'\phi.$$

The solid curves plotted through the data in Fig. 1 were obtained in this manner. The theoretical curve fitted through the simulator data provides an excellent fit of these data. The theoretical curve put through the field test data probably fits the data as well as any regular function. The field test data represent only one-eighth the number of simulator data and, of course, there are a considerable number of additional experimental uncertainties present in the field test data, so that the general erraticness of the field test data is probably not surprising.

Based upon the descriptive adequacy of this construct, the simulator recognition probability data were analyzed to determine if φ varied with either flight altitude or attitude with respect to the sun. Small variations were found, the details of which are presented in the complete report of these studies(1). The data were also analyzed on terms of σ and, again, small variations in the value of this constant were found as a function of flight altitude and attitude with respect to the sun.

Construction of Theoretical Probability Curves for Various Flight Altitudes and Attitudes. Theoretical probability curves have been constructed to represent the field test data to be expected for the various individual flight altitudes and attitudes with respect to the sun. The probability curve obtained from combining all the field test data, which is presented in Fig. 1, was used as the fundamental basis. This curve was described by the three parameters, median log slant range, σ, and φ. The values of these parameters were modified by relative

factors obtained from detailed analysis of the probability data obtained in the simulator. Use of the same modifying factors was believed justified on the basis that the relative slant range values obtained in the field tests and the simulator varied in much the same way as a function of flight altitude and attitude.

Theoretical probability curves are presented in Figs. 4-8, for attitude angles of 3, 45, 90, 122, and 177°. In each case, probability curves are presented for flight

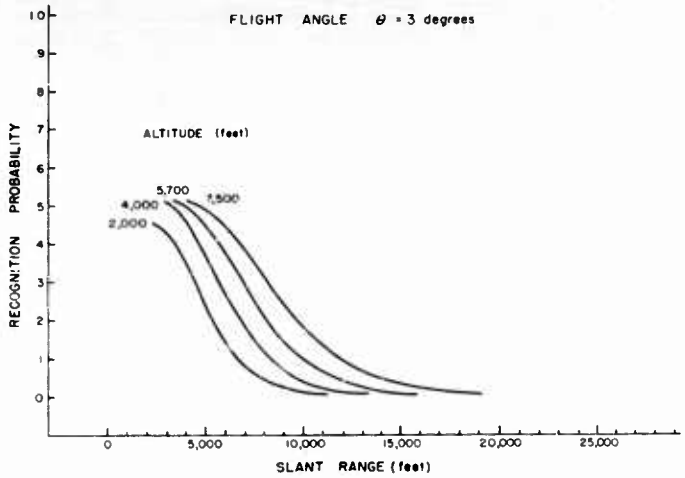

Fig. 4.

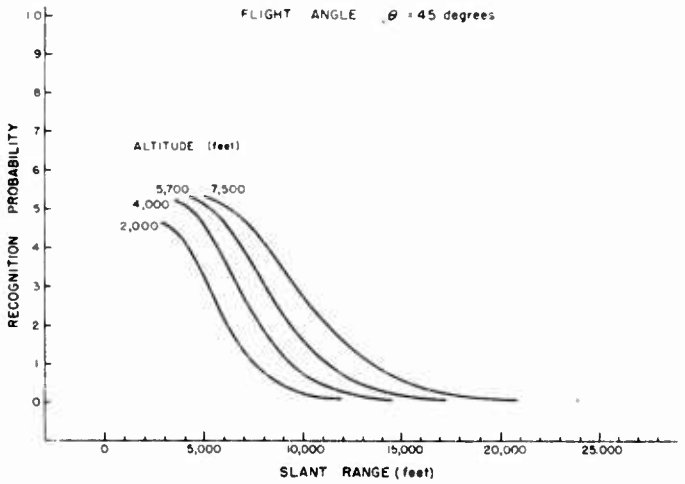

Fig. 5.

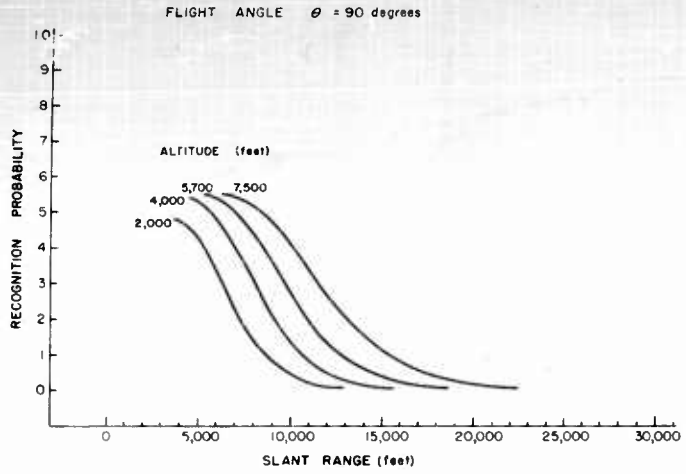

Fig. 6.

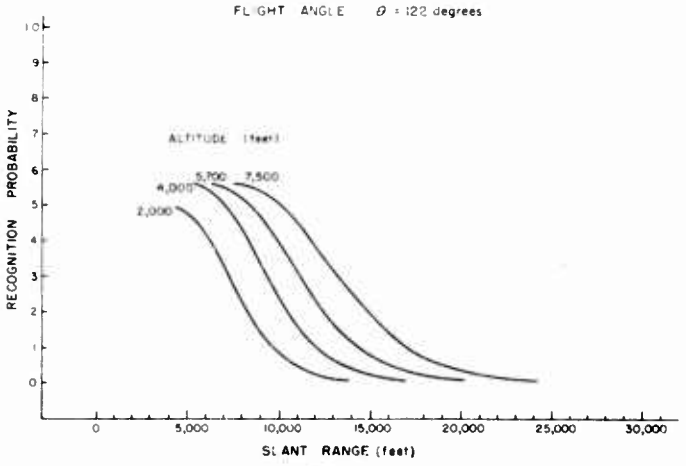

Fig. 7.

altitudes of 2000, 4000, 5700, and 7500 feet. These curves presumably will be valuable in connection with practical visibility problems in which altitude and attitude will generally be known, at least to some extent.

Relations between Detection and Recognition Ranges. As indicated above, it was considered impractical to determine both detection and recognition ranges during the flight tests. However, detection and recognition ranges were determined during the simulator measurements. These data have been analyzed to give some concept of the extent of difference in the ranges obtained with these two visibility criteria. The analysis proceeded by the determination of values of D/R,

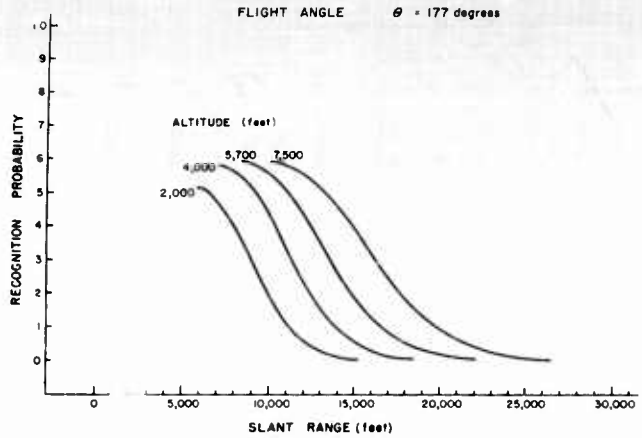

Fig. 8.

a ratio of the detection range divided by the recognition range. Since there was never a recognition made without a detection, nor a detection without a recognition, the probabilities are identical. The values of D/R ratio were summarized by flight altitude and attitude, with the results shown in Table 2.

TABLE 2

VALUES OF THE D/R RATIO FROM SIMULATOR DATA

Altitude (feet)	θ 45°	θ 122°	Average
2,000	1.150	1.259	1.205
4,000	1.188	1.192	1.190
5,700	1.181	1.187	1.184
7,500	1.146	1.090	1.188
Average	1.166	1.182	

It appears that the D/R ratio does not vary significantly with flight attitude, but does show a consistent trend as a function of flight altitude. The fact that the D/R ratio is least for the higher altitudes can perhaps be understood in terms of the fact that the targets exhibit less perspective distortion at the higher altitudes.

If detection ranges are desired, the values in Table 2, may be applied directly to the values of slant range obtained from the theoretical probability curves of Figs. 4-8. This use of the ratios assumes that σ is the same for detection and recognition, an assumption which may be made in the absence of information to the contrary.

REFERENCE

1. BLACKWELL, H. R., OHMART, J. G., and HARCUM, E. R. Field and simulator studies of air-to-ground visibility distances. *Univer. Michigan Res. Inst. Rep.*, 1958, No. 2643-3-F.

DISCUSSION

HENRY A. KNOLL: The authors of the papers just presented are to be complimented on the excellence of their work. We can only regret that more time is not available to learn more about their results.

Discussants of Session I have suggested that mathematical models (or tools) have little value because they lean heavily upon educated guesses, approximations, and assumptions. If these are in fact valid criticisms, then the experimental studies reported in this session are subject to the same criticisms and may be classified as having limited value. I do not agree that educated guesses, approximations, and assumptions destroy the usefulness of these studies or the mathematical models — they simply serve to restrict their usefulness. It is to be regretted that the state of the art has not progressed more rapidly. It is to be hoped that more rapid progress will be forthcoming.

The real danger in these "basic" studies is not the fact that they include educated guesses, approximations, and assumptions, but rather that these will be forgotten by the reader (and sometimes the experimenter) and the data will be used where they do not apply. I think it is in order to point out some of these factors in the papers just presented to you.

1. Restriction of head and body movement — Whenever eye movements are a part of the record, this restriction is imposed. It is to be hoped that techniques will be developed which avoid this. Search with fixed head would apply only in cases involving a mounted optical system, i.e., periscope.

2. The authors, this afternoon, have given numerous bits of evidence which indicate that one may not assume randomness of eye fixations. It would have been convenient, especially for the mathematical models, if this had been the case, but as has already been said — this is a complicated field. Dr. Enoch and Drs. Krendel and Wodinsky have shown that the pattern will vary during a given search.

3. Throughout this symposium it has been assumed that information is obtained only during fixation pauses. There has never been a definitive experiment verifying this oft claimed fact. I feel reasonably certain that some information is gained during eye movements — unfortunately I have no evidence to support this — this is an educated guess.

4. From the standpoint of applying these results to an operational situation, we might criticize the physical comfort of the subjects! This would not apply to photo interpretation or radar watches, but certainly in the cases of air-to-sea, air-to-air and air-to-ground searches. The people who are given these latter types of assignments may at the same time be involved in tasks of piloting or navigating the aircraft. Dr. Blackwell pointed this out as a possible explanation for his result.

5. The reported searches varied in length between three seconds and three minutes — another discrepancy between experimental and operational conditions.

Dr. Baker's paper touched on this very important problem of the operational situation. Maintaining maximum vigilance is a vital problem in sustained searches.

At the present time we seem to have very little data which can be applied "across the board." A few areas have been studied intensively, for example the work reported by Drs. Enoch and Fry, but no really general theory of search has emerged yet. Until more intensive studies are carried out, there is little hope for such a general theory.

In describing the field to be searched such terms as homogeneous, unstructured, partially structured, competitive, imbedded and complex have been used. The data of Mr. White (Session III) and that reported by Dr. Enoch would indicate that in many ways the eye movement patterns are similar even though the types of field are radically different. It is my feeling that one of the first real steps toward a general theory of search will involve the relationship between the eye movement patterns and the type of field involved. Relative movement between the field and the searcher must certainly also play a role in this relationship.

The paper by Dr. Baker on vigilance was of special interest to me — primarily because it was in a field which was quite foreign to any of my own work. In thinking about his paper it occurred to me that a great deal of work has been done, in what might be called the converse of search — namely advertising. The "Madison Ave." type spends his working hours devising methods of visual (and other) conspicuousness — he does everything to make the single glance probability equal to unity. His design is to reveal, not to hide — to reduce search to an absolute minimum. Extensive exposure to such simple visual displays may (and this goes beyond what one would call an educated guess) result in eye movement patterns poorly adapted to difficult search tasks.

WARREN H. TEICHNER: This session, indeed the whole symposium, has convinced me of at least one thing — there is more to visual search than meets the eye. On the one hand, there is the strategy of the search which is a game played between the observer and the target, on the other hand there is the medium of the search, the method by which the strategy is made operational. That strategy which is best in a probability sense may not be the one used. What strategy is used depends on constraints imposed by the medium, in this case visual, and by personal, experiential and environmental conditions. Therefore, visual performance in the search situation is partly a problem in pure strategy and partly a problem concerned with factors which affect the selection and execution of strategies; of the latter, vision is only one kind of factor. My discussion, therefore, will deal with selected comments along this line, specifically with strategies related to field structure, vigilance and search, and environmental factors.

Field Structure

It seems from Enoch's summary that with the aerial photograph, which I shall call a structured display, the natural search process is systematic. His subjects used a strategy, though not the best one. Ford, White and Lichtenstein(2) recently reported a study of eye movements using a fairly large search area which

was embedded within a still larger area of different luminance. This type of display may have some, but not much structure. They found that the search process was initially apparently random, but that with successive search experiences, it became systematic. Miller and Ludvigh, and Krendel and Wodinski used very large unstructured fields. In neither case was the search process studied, rather the end product of search, detection, was measured. In both cases it was possible to describe or predict detection with probability models which assume a random search process. I hypothesize from this that, except for a condition to be noted shortly in free search, the less structured the field, the less consistent and systematic the search until for completely unstructured fields, searching may be treated as random. I do not pretend that this is a novel idea.

Miller and Ludvigh noted the loss of the visual position sense in unstructured fields and suggested that for this reason the observer is unable to perform a patterned search even if he wants to. In fact, their subjects reported that they did intend to search systematically. This is part of what I meant when I said that the medium imposes constraints on search strategies. Gottsdanker provided another example of the working of such constraints when he reported that 16 of 40 subjects did not consistently carry out a sequential search process when so instructed. Apparently there is an interaction between display and personal factors which is another source of constraint.

I said that the carrying out of a search strategy depends on the structure of the visual field. Actually, Miller and Ludvigh introduced a structure into their situation and found that it had no effect. This appears to be a contradiction. I propose to "weasel" out of it by suggesting that there are kinds and quantities of structure and that some may be more conducive to patterning eye movements than others, that indeed, for a given kind and size of field and target and target behavior, there may be an optimum kind and quantity of structure — optimum in the sense that the restraints to eye movements that it imposes, or suggests, lead to an optimum search strategy for the situation. If this is reasonable, then there may be a gain from imposing structures on fields, perhaps through sector or other markings, overlays or viewing devices and profit from studies which determine the optimum structure for various search problems, e.g., radar, aerial photography, air-to-air search, etc.

All of this makes nice "music," at least to me, but perhaps you recognize certain elements of confusion. Among these is the problem of structure itself. I am willing to say that Miller and Ludvigh have an unstructured field. I am not sure of what I mean when I talk about a structured field except, perhaps, that there are elements within the field which affect the pattern of free eye movements. There is really an important need to study the geometry of visual structure in this sense. This type of research which might be called *visual geography* does not seem to be receiving direct attention. It is getting inspired trial-and-error attention, e.g., Enoch, but a quantification of structure is needed to develop a systematic approach. Another approach is automatic scanning. I am impressed by the possibilities offered by this device, at least, as Townsend and Fry note, for relatively low visibility conditions. These are, perhaps, poorly structured conditions

and maybe built-in structuring might lower the point at which the scanning method should be automatic. My only hesitancy about automatic scanning comes from psychological questions. What happens to this type of visual tracking when the observer is suddenly stressed or when he is fatigued or bored? Do his eyes leave the scanner? Does he revert to a more natural search process?

Vigilance and Search

The vigilance or monitoring study can be thought of as a special case of the search study; it deals with targets restricted in location and puts the emphasis on temporal variations. With this as an approach I shall use Baker's study as a basis for raising certain questions about other search studies.

Baker pointed out that in the typical vigilance study there is a systematic decrement in the proportion of signals detected as a function of time; the greatest percentage loss occurs in the first half-hour. I would guess that the typical search study, for example those reported to this symposium, requires the subject to perform for an hour or so. For example, Krendel and Wodinski, and Miller and Ludvigh used one hour sessions. Now considering the usual vigilance study results, why is it that these search studies do not find a marked and systematic decrement in the proportion of targets detected during the experimental session?

A partial answer to the question lies in the fact that the typical search study interrupts the observation after each detection and, as far as I can determine from Krendel and Wodinski, and Miller and Ludvigh, the subject is provided knowledge of results. According to Baker, and also very recently Garvey, Taylor and Newlin(3), this prevents the decrement. Baker says that it confirms an expectancy. However, I think that there is more involved here and I shall return to this point shortly.

Expectancy, a concept closely related to subjective probability, is said to depend on the apparent rate of signal presentation and the regularity of the inter-signal interval. I shall assume that expectancy is similarly related to location of target. As targets or signals are missed, even though delivered systematically, the apparent regularity of target events decreases until, in the later stages of the vigilance task, target events are apparently random, expectancy approaches zero, and detection is no greater than chance. Now in the typical search study target events are delivered randomly so that even if the observer has an expectancy, it will not help him and presumably he loses it rapidly. The situation throughout the search study is the equivilant of that at the end of the vigilance study. Returning now to the question asked earlier, this may be why search studies do not find a decrement during the experimental session: the observer's expectancy is at or near zero very quickly and, consequently, his detection is at a chance level from the very beginning. I suspect that the function of knowledge of results is motivational in this case, i.e., it keeps the observer observing and thereby maintains his performance at chance.

Along this line, is it true that all military search problems involve random target events? Is the probability of target appearance the same at all points of a

radar scope, an aerial photograph, the sky seen from a given position, etc? I think that random presentation is used mainly as an experimental control to keep the observer from developing an expectancy. But if his expectancy is zero, then why should we expect him to use an efficient search strategy?

In Miller and Ludvigh's situation target events were random. How much of the poor performance observed was due to a loss of position sense and how much to the random presentation? Is this why the structure tested had no effect? If the observer were given repeated experience with patterned target events, wouldn't he develop an expectancy and a patterned search even in an unstructured field? Perhaps automatic scanning might do the same or both might be used together. I raise these questions because of their obvious implications for training in visual search.

Environmental Factors

Clearly any environmental factor which affects visual function as an obvious physiological consequence provides a serious threat to successful visual detection. For example, it is well known that altitude, acceleration, carbon monoxide, and vibration reduce visual effectiveness. In fact, reduced visual sensitivity is perhaps the most sensitive indicator of these effects. Intellectual functions, and so strategy and/or searching methods, are impaired at significantly greater levels of these factors. However, it is not with critical levels of physiological effects that I shall be concerned. Not that I wish to discount the importance of such problems; I don't. But the importance of these problems is generally recognized whereas the importance of more subtle psychological effects is often ignored. It is about psychological effects, therefore, that I wish to continue my speculation.

Baker touched on the general problem briefly when he noted that temperature and high ambient noise levels reduce the effectiveness of monitoring. I think though that Baker dismissed environmental factors too easily when he said, "The explanation of these effects is simply that any distraction which competes for attention with the vigilance task will lower the apparent signal frequency and consequently result in reduced performance." Is this true? Is high ambient noise, constantly present, a distractor or is a *change* in the ambient noise level necessary before we can talk about distractors? If an environmental condition can be said to compete for attention, it must have something to offer in competition. Isn't this some kind of personal threat? If so, then isn't the basic question not one of distractors, but one of motivators?

Consider the following experimental question. A control group working at a vigilance task in a continuous, high level noise field is to be compared with an experimental group under the same conditions except that after every few correct detections the noise is briefly reduced or interrupted. Which group will detect more signals? Which group will have the greater rate of decrement? This exact experiment has not been done although one incorporating it is now in preparation. There is reason to expect that the experimental group will do better; in fact, if properly set up, it may not show any decrement. This expectation is based on recent work by Azrin(1) using noise and the observing response in a vigilance situation and by Peacock and Marks(4) using heat as a reinforcement for bar-

pressing of rats in a cold-box. This result can also be derived from learning theory by making a few assumptions and from the expectancy concept, if forced a little. The point is that in all cases, it is equally reasonable to postulate the presence of a motive related to escape or avoidance of the noise or other environmental condition and it is this motive which competes with whatever motivation is related to task performance. Studies demonstrating learning based on relief of environmental stress are strong support for this view.

This leads to the possibility of turning the competing motive to work by scheduling noise reductions or other environmental reliefs, that is, rewards, for desired levels of task performance. Of course, there are associated questions, e.g., habituation and adaptation to the environment and methods by which these can be manipulated to minimize performance losses. Granted that these problems are non-visual, I don't think that they are out of the context of the symposium. Environmental factors and other operating conditions are sources of constraint to the strategy of the search and the maintenance of search-detection levels.

In conclusion, in an effort to integrate my own discussion, I shall list what I believe are the six major areas of further research on performance in the search situation. In doing this I shall "sneak" in some points that time did not permit me to discuss.

1. Studies of strategy: What is the best strategy for different search problems? What strategy is next best, etc.?

2. Studies of the visual medium: In what ways and to what extents do display and/or field variables and the limitations of the visual apparatus affect the selection and use of strategies? Importantly included here is the problem of visual geography.

3. Temporal variables: How does the length of time available for detection and the length of time that the search is prolonged affect the selection and use of strategies. This must be considered in terms of processes which go on in time as well as simple time functions.

4. Environmental variables: How do environmental and other operational conditions influence psychological and physiological processes and the development and successful use of strategies?

5. Personal variables: What kind of person makes a good strategist? How do intelligence, motivation and learning affect the development of strategies?

6. What methods, both human engineering and training, can be developed to enhance visual search?

REFERENCES (Dr. Teichner's discussion)

1. Azrin, N. H. Some effects of noise on human behavior. *J. exp. Anal. Behav.*, 1958, **1**, 183-201.
2. Ford, A., White, C. T., and Lichtenstein, M. Analysis of eye movements during free search. *J. Opt. Soc. Amer.*, 1959, **49**, 287-292.
3. Garvey, W. D., Taylor, F. V., and Newlin, E. P. The use of "artificial signals" to enhance monitoring performance. *USN Res. Lab. Rep.*, 1959, No. 5269.
4. Peacock, J. L., and Marks, R. A. Behavioral concomitants of cold adaptation: I. Rate of responding at 2.5° C. AMRL Rept. 283, June 1957.

SUMMARY AND DISCUSSION

R. M. BOYNTON: The papers that we have heard during the past two days have provided an excellent opportunity for us to learn about the present status of research effort on the subject of visual search. This seems very valuable, because much of this work is still confined to limited-distribution technical reports, and only a part of it has been published in the more accessible journals.

One of our stated objectives has been to provide information that will be useful to the military in the development of optimal visual search technique. I personally feel that we are still at some considerable distance from this goal, and that for some time to come, the solution to practical problems of search will continue to be more of an art than a science. This will continue, I think, until we have developed a satisfactory general theory of search which can be used as a guide for the solution of practical search problems.

A satisfactory general theory of search is in turn not likely to be developed until a sound body of empirical knowledge has accumulated which can provide the foundation for theory construction. Unfortunately, the theories of search reported here during the last two days have suffered greatly from a failure to take into account experimentally-based information already available. This is especially true with regard to the matter of eye movements.

I would like, in my summary, to review some of this experimental information and attempt to evaluate it. I hope that you will excuse me if I introduce, where appropriate, information gathered at Rochester from three years of psychophysical research on searching and recognition which I have not had the opportunity to report at this meeting as such(1). (Reference(1) is on page 250.)

Eye-Movement Experiments

We have heard about eye movement recording work from Dr. Enoch, Mr. White and Dr. Mackworth. Their work of course verifies that, when an observer is looking for something, his eyes move in a discontinuous fashion, so that information is gathered from the visual environment in a succession of discrete fixations separated by very rapid eye movements. Their work also indicates that the length of time per fixation is on the order of a third to a quarter of a second.

From the reports given by Drs. Volkmann and Fry, the conclusion emerges that, the more fixations per unit time — at least up to some limit — the better chance a subject has to detect a target. This interests me very much, because it relates to a brief study that we did in 1957, with the cooperation of Dr. Enoch. At the conclusion of our psychophysical searching-and-recognition experiments, we journeyed to Ohio State with two of our subjects — our best and our worst (based on their ability to find and to recognize critical targets). Although we had some technical difficulties with the recording procedures, we were able to infer from the records that our poorest subject averaged about 0.33 second per fixation, whereas our best subject averaged only 0.20 second per fixation. Both were looking at the same visual search material which had been used at Rochester, and

under the same conditions of reward. The better subject also made larger eye movements.

This evidence is only suggestive, but is seems to tie in with what we have heard from Fry and Volkmann. It indicates that one of the causes of individual differences in searching ability is fixation rate, and suggests further that a given individual could learn to search more effectively if he somehow learned to make more fixations per unit time.*

We have head some conflicting information from Enoch and White with regard to *where*, in the visual field, the subjects tend to concentrate their fixations. Enoch's results show such a concentration in the center of the field, whereas White's data indicate more fixations at the periphery. We may postulate that this discrepancy mainly reflects differences in the experimental situations. In particular, Enoch's subjects were looking at structured fields (map-like displays) whereas White's subjects were searching an empty visual field and looking for a single target. This matter would seem to deserve further experimental attention.

We have not heard any comments with respect to the percentage of the total search time that is occupied by fixations; some indication of this from Enoch, White, and Mackworth would, it seems to me, be in order. It is my impression that this figure is on the order of 85 to 90 per cent. I would like to inquire also into the accuracy of the methods used. Dr. Mackworth was talking about reliability on the order of a minute or so of visual angle. White and Enoch did not comment on this, so far as I can remember.†

The next thing that I would like to comment about concerns a point which Dr. Harris first raised yesterday, when he said that what we would really like to know, as far as optimal search techniques are concerned, is something like this: Given that a subject is looking at a particular point in the visual field at a particular moment, what would be his optimal point of regard for the next fixation? Now this is the kind of analytic stuff out of which a visual search theory might be built, and yet there are certain fundamental problems involved in looking at the question from this point of view, which may apply better to a game of chess than to a problem of search.

For one thing, it is evident that, at the rate of three to five fixations per second, there is not enough time for impulses generated by the action of light upon the visual receptors to be delivered to the visual cortex and/or other cortical areas where decision-making is mediated, and then for impulses to be sent back to the eye musculature to control the location of the next fixation. This matter of eye movements during visual search seems rather similar to the problem of finger

*A group of procedures which presumably succeed in doing this are those used in improving reading rate. It would be interesting to know whether there is a correlation between reading rate and searching ability, and, if so, whether the effects of remedial reading training would transfer and improve performance in the searching situation.

†"Dr. Enoch states after the meeting that his data indicated reliability of $\pm 0.1°$ standard deviation, and in most instances validity of better than the required $\pm 0.25°$ standard deviation. This is very encouraging, since what is needed for some purposes is a technique which can record large eye movements as well as small ones, both with great accuracy."

movements in the playing of the piano. In either type of activity, impulses from cortical centers can represent only some kind of general strategy, or plan, whereas the details of how the attack is carried out must be elaborated by lower centers, and must involve reflex circuits which are much shorter than those involving cortical areas and decision-making processes. Dr. Fry has already suggested that the parafoveal "conspicuity" of a critical target may be an important determinant of what the eyes are going to do next. It seems likely that, given a particular type of target being sought, and a particular general strategy of search, the eyes are successively attracted to areas which on the basis of off-foveal cues seem to signal a relatively high probability of a critical target being there. The final identification, of course, involves a positioning of the image of the target squarely in the foveal center, where detail vision is high. (Even then, the identification may not be made, as was clearly evident in some of Dr. Mackworth's beautiful motion pictures).

I would like to comment next on the influence upon eye movements of factors of past experience, previous perceptual learning, the application of intelligence information to the searching task — in short, what Col. Hauser referred to yesterday as "mental analysis." At this point, we seem to know very little about what (if anything) a highly trained observer, such as the one Hauser talked about in his lengthy but important example yesterday, is actually doing with his eyes as such which would improve his performance over that of the novice in the same situation. Enoch's evidence that experienced photointerpreters do not seem to exhibit significantly different eye movements, nor significantly better visual performance in the searching situation when compared to untrained observers is somewhat puzzling. This result would, however, seem to suggest that the most important kind of information that is needed for an observer to achieve optimal search is not a book of rules about "How to Search," but rather a solid background of information and sophistication about the specific environment which is to be searched.

Theories such as those of Lamar, McGill, Krendel, and Harris seem to suffer from four major limitations:

(1) Failure to pay attention to the facts about eye movements.

(2) Disregard of psychological factors of the sort just mentioned.

(3) Identification of *detection* with *recognition*.

(4) Failure to appreciate complications which can occur when multiple targets are in the field of view.

The distinction between detection and recognition has already been well covered by Arnoult. Without going into details, I should like to report that we have found experimental conditions where the introduction of only one irrelevant form to a tachistoscopically-viewed field reduced the probability of correct recognition of the relevant form from 40 per cent to *zero*. Even disregarding Hauser's "mental analysis" factors, the interaction effects within highly-structured, real-life visual fields seem so complex as to defy even preliminary description.

Psychophysical Experiments

The studies of Miller and Ludvigh are most interesting, and certainly important, whether or not one wishes to accept their conclusion that faulty accommodation is not involved in the extreme difficulty had by their observers in searching out a single target in a uniform field. There appear to be two important factors at work here: (1) The extremely low peripheral conspicuity of these targets, and (2) The tendency for hallucinatory percepts, mentioned by Cohen, to arise in so impoverished an environment, and to act as background noise to make the detection still more difficult.

If I interpret the data of Drs. Green and Krendel correctly, each appears to have discovered in their work a most interesting relationship which we have also observed at Rochester: the value N/t is a constant. This means that the number of confusion targets which a subject can search per unit time, with criterion success, is independent of the search time or number of such irrelevant targets, so long as the N/t value is unchanged. In other words, an observer can perform just as well (stand the same chance of locating and recognizing a critical target) with 64 confusion forms and 12 seconds to search as with 128 confusion forms and 24 seconds to search.

This relationship seems to hold only if the subjects are encouraged to work hard, to search diligently during the entire period provided. Krendel has fitted his data with straight line functions which hold up for relatively short exposure periods but which do not fit the data for longer periods. During the first year of our searching-recognition work at Rochester, we found that the N/t constancy did not hold for exposure times beyond 12 sec. Then, by observing our subject's behavior (as Dr. Baker would recommend), and by post-experimental interview, it became evident that our observers were quitting after the first 12 seconds or so. In later work, we were able to induce the subjects to keep working, and we found the N/t held constant for 24 seconds, at least. We may then conclude that the N/t constancy works only if the subject is actually utilizing the full exposure period to the best of his ability; if he does so, we find that the relationship holds almost exactly.

I think that an important point can be made using this N/t relationship as an example — a point concerning the erection of visual search theory upon a foundation of psychophysical data alone. What would be the most reasonable starting assumption to make, given that N/t is found to be constant? Clearly, if one assumes that what the subject does is to search each confusion target in turn, without repetition, and with the same probability on each fixation of recognizing the critical target, it would directly follow that N/t *should* be a constant. In other words, if a string of forms to be searched were doubled in length, the position of a random critical target would, on the average, occur twice as far from the start of the string. Attractive and simple as this line of reasoning may seem, we know perfectly well, on the basis of eye-movement records, that the observer is doing noting of the kind. Actually, the N/t constancy must depend upon the complex interaction of much more complicated variables.

Whatever the cause of the N/t constancy, we might nevertheless be able to take advantage of it. The variable *N*, which in the laboratory indicates the number of background forms among which the critical target is located, corresponds in real life to what we call the "complexity" or the "clutter" of the background. Gottsdanker, in his experiments, produced realistic material of this needle-in-a-haystack variety, but was unable to specify the complexity of his backgrounds except in a qualitative sense. The point is, that to the extent that N/t is constant, the relative complexity of various realistic or real-life backgrounds may be quantitatively specified in terms of the mean search time required to find a critical target.

Other important physical variables involved in search include the contrast between the targets and the background, the size of the target being searched, the luminance of the targets and their background, etc. This list could be extended but these are the ones which have been dealt with in the laboratory for the most part. More complicated factors such as target movement, internal contrast differences, deliberate camouflage, the effect of angles of illumination, and shadows, have been much less investigated. In fact, Blackwell has found it necessary to go to a simulation study in order to evaluate, for practical purposes, the effects of these variables.

We have heard it said that the more complex the background, the worse is performance; the longer the subject has to look, or the higher the contrast between the forms and background, the better is performance; and the higher the luminance of the background, or the bigger the targets, the better is performance. These findings are rather obvious ones; if experiments were to turn out otherwise, we would certainly be much surprised! The critical thing that we need to know is the interaction among these variables. The bulk of our work at Rochester was concerned with an effort to determine the interaction between: (1) number of background forms, (2) search time, (3) contrast, and (4) target-object distance. In the third year of this research, we determined experimentally the combinations of these four variables required to elicit 60 per cent correct recognition from the subjects. We were able to work out an empirical equation which described our results to within 11 per cent accuracy. The equation is:

$$\log (C - 2.34) = 0.0857D + 1.565 \log \left(\frac{N}{t} + 3.021 \right) - 1.52 \qquad (1)$$

where C is contrast in per cent, D is distance in meters, N is the number of "struniforms" (confusion forms) in the background, t is the search time in seconds. (The typical target subtended about three centimeters.)

It is possible to take this equation and plot the data in a form which makes them directly comparable to the contrast threshold data of Blackwell. This has been done in Fig. 1, where Blackwell's contrast threshold data are for negative contrast and a 10 mL background. Blackwell's curve is compared to results based on Equation (1) for various values of N/t ranging from 0 to about 50. From these curves, one can see the effect of introducing background clutter upon target recognition.

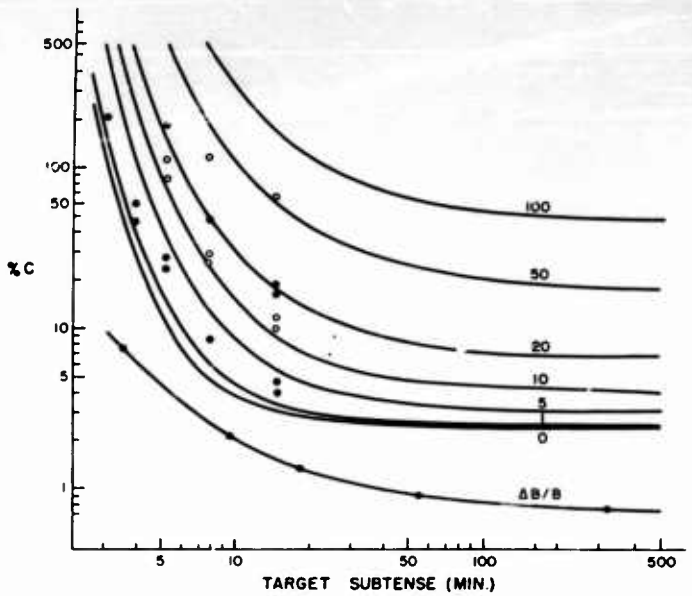

Fig. 1. Per cent contrast vs. target subtense (log-log plot) for Blackwell's threshold contrast data (10 mL background, single circular test object, negative contrast) compared to results of experiments by Boynton, Elworth and Palmer. Blackwell's is the lowest curve. The parameter on the other curves is the N/t ratio (number of confusion forms to be searched per unit time).
In order to relate these curves to the experimental data, some of the experimental points have been included. The bottom black points are for an experimental N/t ratio of 2.33, and the points fall between the curves for N/t = 1 and N/t = 5. The open circles in the middle are for N/t = 10.33, and these may be seen to lie slightly above the curve labelled "10." The next set is for N/t = 20.33, and the open circles at the top are for N/t = 42.67.

A crucial question regarding our work, and that of many others, concerns the nature of the particular forms used. Ours were quite arbitrary. It is to be expected, for example, that the more similar a critical target appears when compared to the confusion forms, the lower will be performance for a given set of conditions. The important question actually is whether the interactions among the major variables will hold up for changes in target character, target luminance, and other variables which have not yet been explored from this point of view. For certain targets, we now have a fair idea of the interaction among some of the major variables in simplified laboratory situations. We cannot, however, say with certainty how this applies to real-life situations.

Applications

My final remarks will concern the possible applications of some of this work. In the absence of an adequate general theory of search, one must proceed by

making assumptions and then by calculating from available psychophysical data. Drs. Blackwell and Lamar have told us how they did this sort of thing, and I would like now to tell you how we went about it.

Having determined an empirical equation which summarized the interactions among our four main experimental variables, it was possible to translate from this to practical situations by making certain assumptions:

(1) The relationship between the angular size of an object in the laboratory and the angular size of an object when viewed from an airplane is linear and rather obvious.

(2) Contrast is a potent variable affecting search ability, and is significantly affected by weather conditions. We based our analysis on Duntley's optical standard atmosphere and made calculations for various assumed meteorological conditions (expressed in terms of the atmospheric attenuation coefficient and the sky-ground ratio in various combinations). This told us what the effect of these meteorological variables would be upon contrast at various assumed altitudes.

(3) Speed of aircraft relates laboratory time to real-life time. Since our data referred to small search areas, we made this translation by assuming that the pilot detects a general area of interest which is located 45° ahead of his plane and 40° to the side. He picks up this area and searches within it until it comes directly alongside the plane. On this assumption (or any other similar assumption), the length of time the pilot has to search is inversely proportional to aircraft velocity and directly proportional to altitude.

Therefore, as altitude increases, contrast decreases and angular object-subtense also decreases — both of which tend to reduce performance; search time, however, increases — which tends to improve performance. (We made no assumptions pertaining to the influences of target motion *per se* on performance and this is important at low altitudes where the relative angular velocity of objects is high).

What was done was to solve for N, which was the number of confusion forms in the laboratory, which translates to background complexity or area of search in real-life. We solved for N for 60 different altitudes, a number of inherent object-background contrasts, several assumed weather conditions, and two aircraft velocities — obtaining in all more than 100 functions of N vs. altitude. A sample is shown in Fig. 2.

On the basis of these calculations, we drew the following tentative conclusions:

(1) All functions exhibit maximum and show a cutoff altitude (the latter taken as the altitude where N becomes 1). There is, then, an optimal altitude for search.

(2) Cutoff altitude is about 2.7 to 4.3 times greater than optimal altitude, and the ratio of these two is largely a function of inherent object-background contrast and is nearly independent of object size and meteorological conditions.

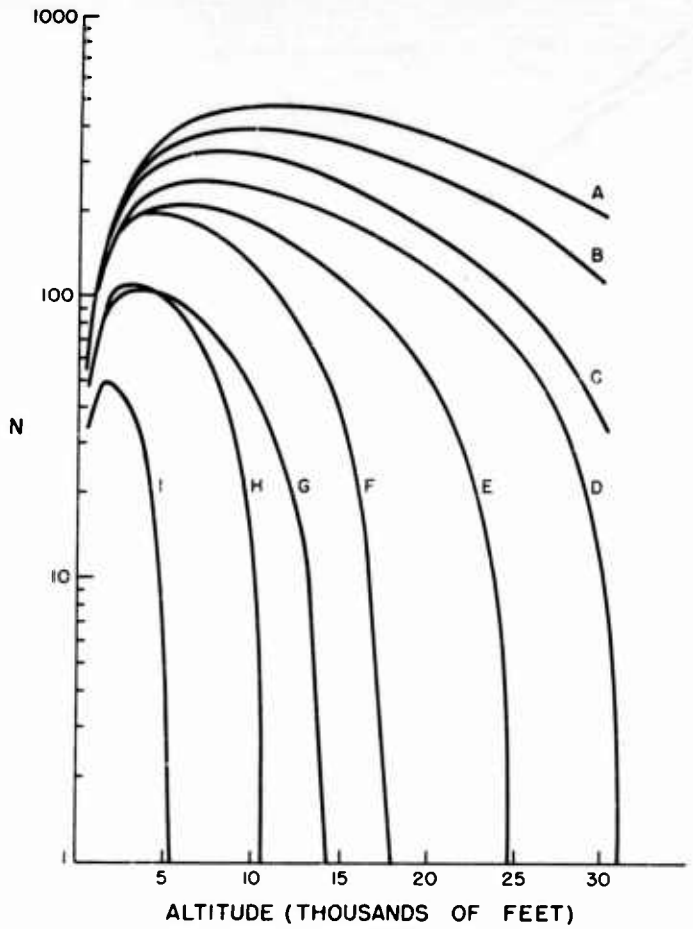

Fig. 2. Performance (N) as a function of altitude, calculated from laboratory data according to certain assumptions (see text).
From top to bottom, curves are for progressively less favorable conditions of visibility based upon assumptions concerning meteorological conditions.

(3) Optimal altitude is a complex function of all other variables. Under the best conditions of visibility it is on the order of 250 times the linear size of the object being sought; under the worst conditions of visibility, it is on the order of 30 times the size of the object being sought.

(4) Performance at optimal altitude is directly proportional to object size. The constant of proportionality is independent of contrast, but varies as a function of

meteorological conditions. The worse the visibility conditions, the smaller is the constant of proportionality, and thus the better is performance for small objects compared to large ones.

(5) Cutoff and optimal altitudes are virtually unaffected by changes in aircraft velocity, though performance at the optimal altitude decreases in direct proportion to aircraft velocity.

(6) The influence of inherent contrast upon the cutoff and optimal altitudes is slight until contrast is reduced to well below 50 per cent. Further reductions in contrast then reduce both cutoff and optimal altitudes considerably.

(7) The effect of reducing the inherent contrast of the object being sought is independent of all other variables. A single table can therefore indicate the rate at which performance drops with the reduction of inherent contrast.

It is up to the military to decide whether these conclusions, and those made by others on the basis of laboratory data, will hold up under field testing or make sense in terms of current beliefs. They are, at least, specific statements based on laboratory evidence and certain translative assumptions which might improve search by helping a pilot to choose the best altitude at which to fly for the task at hand. I have tried to avoid Dr. Arnoult's justified complaint that speakers have not been explicit enough about the inferences that might be made from their data.

In conclusion, I would like to thank Dr. Morris for providing me with the opportunity to make these summary remarks, and to congratulate her for a job well done in putting together this most interesting program of papers.

S. Q. *DUNTLEY:* I have been thinking about what this symposium has covered and it seems to me that it has brought out (1) that there are visual search problems of great importance to the Armed Forces, the Coast Guard, the airlines, and many others; (2) that there are in existence methods and data which have already dealt successfully and usefully with some of them, and (3) that relevant research of many kinds is being carried out by many investigators in many places. Although scientific accounts of these researches sound rather complicated (and any research description often does when details are discussed) the important thing is that research is going on and progress is being made.

The engineering method for finding solutions to visual search problems is undergoing rapid development, not all of which has been brought out in this symposium because it has been only a two-day meeting. It is my prediction that if another symposium on visual search is held by the Vision Committee five years from now, or perhaps only two years from now, it will be found that tremendous strides have been made in our ability to deal with search problems. I believe that the biggest effect will come through the coding of large computers for the use of existing knowledge and the calculation methods of the type pioneered by Lamar. It must be remembered that these methods in the hands of O.E.G., the Air Force, the Army, the Navy, and others have produced useful results which have been field tested and are valuable. Although this work may be primitive compared with what can be envisioned, it exists and it has produced worthwhile results; we have something useful today.

The military often run field tests and exercises which are designed to answer search problems. These field tests are of maximum value when the seeing conditions are sufficiently well documented to enable untested circumstances to be judged in terms of those that were tested. The techniques and the instrumentation to do this has had a tremendous development during the past few years. Valid field testing is much more possible that it used to be.

Simulation techniques and simulators have improved and have their place among the techniques available for investigating visual search problems.

Some of the panel speakers who are going to follow me will, I assume, have more to say about the specific prol s that were outlined by the military representatives in the first session. You will recall that Coast Guard problems, air-collision avoidance problems, space vehicle recovery problems, and many others were mentioned. It seems to me that nothing which has been said in this symposium provides direct answers to these problems, but this was scarcely to have been expected. Virtually everything that has been said here, however, relates to the solution of the problems in one way or another. I feel confident that the individuals who raised the problems have gained information from what has been said and that they are in a position to gain a great deal more in the future, for the engineering art of visual search prediction is useful today, is progressing, and will progress faster in the next few years.

R. C. OLDFIELD: I would like, first, to thank very gratefully the Vision Committee for inviting me to this meeting and for making it possible for me to come. I am afraid my immediate contribution is a small one, but the opportunity of being here will allow me to carry back a great many ideas which will be very valuable in connection with research projects in Oxford on visual functions concerned with closely related problems.

Faced as we have been these two days with a rich variety of experimental and analytic work on visual sea (and, as it has seemed to me, on a number of topics as well which are of wide import than search alone), I have found it not easy to maintain my grip on any simple framework of ideas in which these valuable data and analyses can be inter-related. Personally, my reaction to this intellectual stress has been to regress to earlier thoughts of a number of years back, when I was searching for such a framework myself. Perhaps it may not be entirely redundant to outline this — obviously over-simplified — scheme as a way of keeping the essential situations and the inter-relations of the variables in mind, and of defining problems for attack. But I apologise at the outset for the extremely unsophisticated mathematics I propose to use.

Before I do this, however, I would like to throw in a small, but I hope fresh, contribution to technical resources in this field. A number of previous speakers have referred to the design of *search tasks* for use in the laboratory. The following, devised a number of years back, may perhaps be of use to some people working in this field. A specimen of this task is shown in Fig. 1. The subject starts at any circle and reads the lower number aloud. Supposing he has been instructed to start at the circle in the top left-hand corner. He now searches for the circle con-

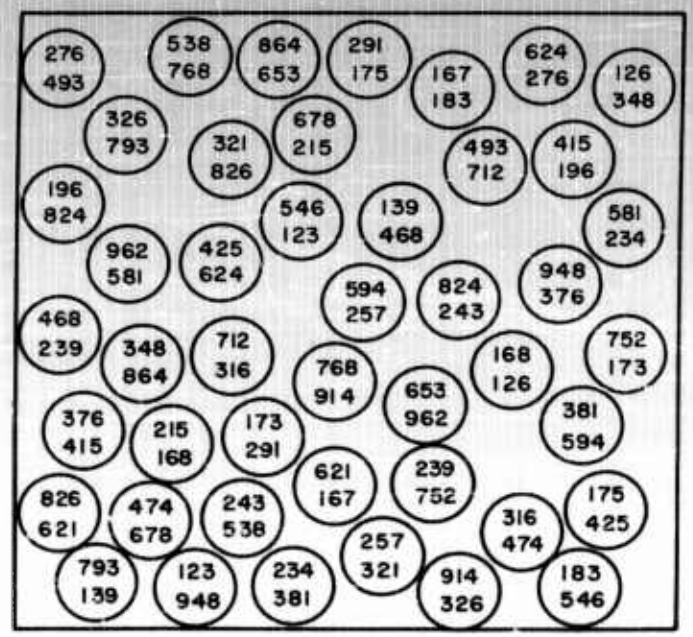

Fig. 1

taining 493 in the upper position, reads aloud the lower number, and looks for the circle which has tnis number in the upper place, and so on. In this particular specimen there are 45 circles and the series leads back to the first circle. The circles are irregularly placed to discourage systematic scanning. The time taken in normal conditions is about five minutes. A number of parameters of the task can be easily varied, and it can be applied in a wide variety of experiments.

Returning to the general analysis of search-activity, I noted that a number of speakers, Dr. Lamar for instance, tended to take it for granted that nothing of consequence to object-detection happens except during fixations, and that we need to consider only (1) the patiern of these and (2) the probability that the object is seen during each. Certainly I used to feel convinced of this myself, and I would still suppose that these are the major factors. Nevertheless there remains the possibility, which ought to be kept in mind, that during an interfixational saccade the *presence* of the object may be *detected* by the summational stimulus arising from the tracking of its image over the retina. Even if it cannot be *specifically localized* at that instant, such stimuli arising during eye-movements might serve to narrow the search. But it is not easy to see how one could get evidence of this, and I propose to take no further account of this possibility.

It has become customary, since Craik's original work, to express the situation during each fixation in terms of a zone of detectability. This is clearly sensible and

convenient in the particular military problems with which he and others were concerned. But in a number of connections, for instance searching a radar screen, all objects are at virtually the same distance from the eye, and in addition we may be concerned with search efficiency for targets whose probability of detection even at the point of fixation does not approach unity. I prefer, therefore, a more general form of the detectability-function which expresses probability of detection at any point (h, k) in the search field in terms of the probability at the fixation point (0, 0) and the co-ordinates of the point (h, k). Confining ourselves to search along a line, the function is something like that shown in Fig. 2, its form being probably sufficiently well expressed by a single parameter, such for instance as the width at half height. (In passing I would like to agree with Dr. Lamar who I think remarked that we still lack adequate and comprehensive data for the detectability-function which is obviously of absolutely fundamental importance in the discussion of visual mechanisms generally).

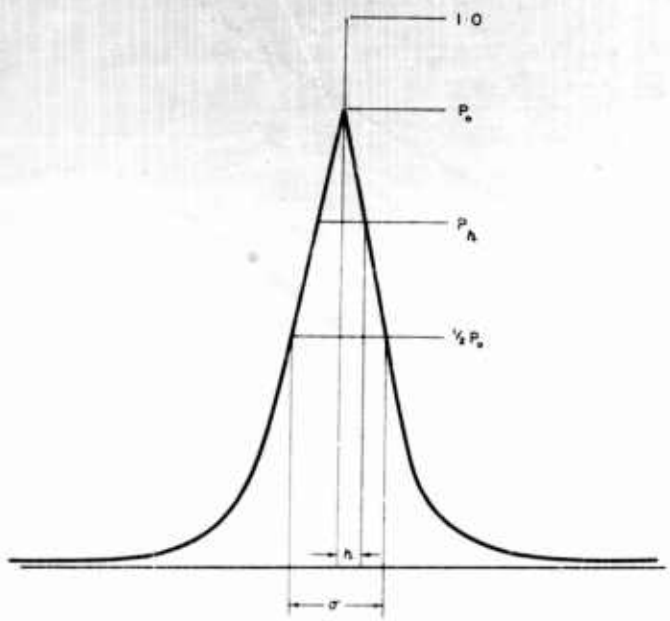

Fig. 2

Turning now to the effect of a number of fixations, the probability that an object randomly situated in the field will be detected in at least one of a number n of fixations is

$$P = 1 - \prod_{i=1}^{n} (1 - p_i)$$

where p_i is the probability of its detection in the i-th fixation. If the i-th fixation point is at x_i in the search field, and the object happens to be at x, then

$$p_i = F(x - x_i)$$

where F is the detectability-function. The expected value of P is

$$\overline{P} = \frac{1}{X} \int_0^X \left\{ 1 - \prod_{i=1}^{n} (1 - p_i) \right\} \cdot dx$$

where X is the extent of the search-field. [The second moment about the mean, $\overline{(P - \overline{P})^2}$, is also of interest as affording a measure of the evenness of field-coverage]. Such a function is obviously difficult to handle by elementary methods. For present purposes, to get a rough idea of the interplay of factors, let us simplify the detectability-function to the triangular form of Fig. 3.

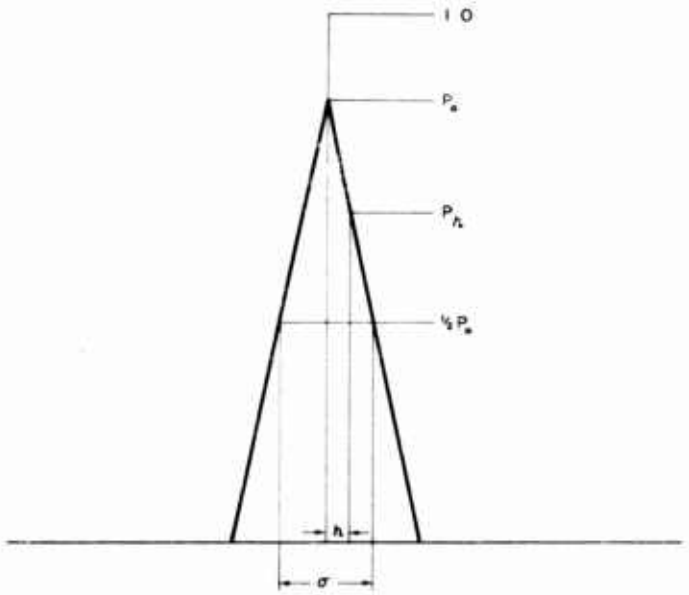

Fig. 3

In practice the fixations are not evenly spaced, but suppose them to be so in the first instance (Fig. 4). Taking a field of unlimited extent (to avoid boundary corrections) it is clear without integration that if $\mu > \sigma$, and the fixation-fields do not overlap,

$$\overline{P} = \tfrac{1}{2} p_0 \cdot \frac{\sigma}{\mu}$$

or, writing λ, the 'fixation-density,' for $\frac{\sigma}{\mu}$,

$$\overline{P} = \tfrac{1}{2} p_0 \cdot \lambda$$

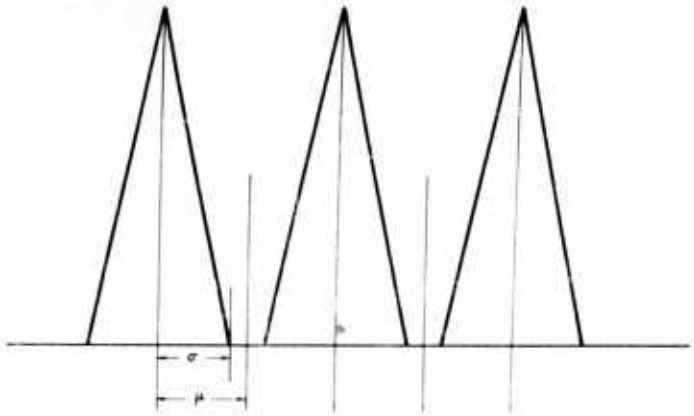

Fig. 4

It is clear in this case that, provided there is no overlap, the fixations need not be evenly spaced, $\overline{P}$ remains unchanged.

Thus, when λ is negligible, $\overline{P}$ is negligible. As the fixations are placed closer and closer together $\overline{P}$ rises linearly with λ to the point where the fixation-fields just touch and extend over the whole search field ($\lambda=1$). As λ increases further, adjacent fixation-fields begin to overlap and the situation is as in Fig. 5.

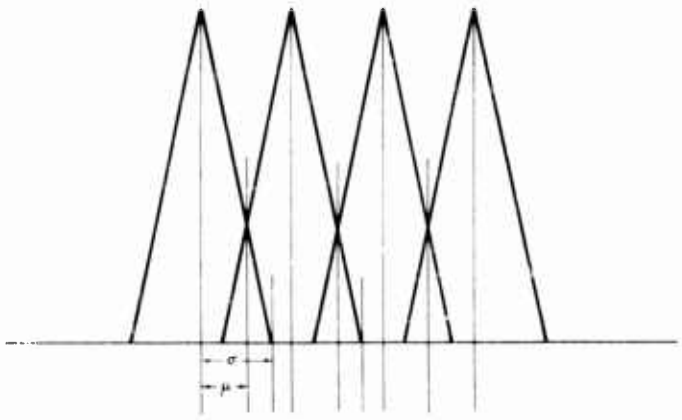

Fig. 5

The expected value of P, for $1<\lambda<2$, now becomes

$$\overline{P}=\tfrac{1}{2}p_0\lambda-\tfrac{2}{3}\cdot p_0^2\lambda\left(1-\frac{1}{\lambda}\right)^3$$

These relationships are shown graphed in Fig. 6.

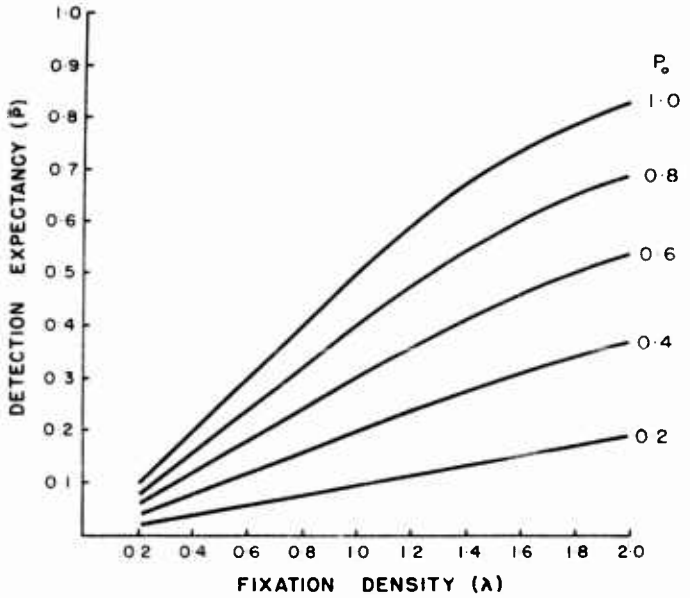

Fig. 6

When $\lambda > 2$, and each detectability-field begins to overlap with its next neighbor but one, the algebra becomes very tiresome, but the general trends seem to be already clear.

These are:

(1) That to raise the expectancy of detection beyond $\frac{1}{2}p_0$, overlap is necessary.

(2) But overlap *in itself* is wasteful, and the rate of increase of expectancy of detection with increasing fixation-density falls increasingly short of the value $\frac{1}{2}p_0$ which obtains before overlap intervenes.

It would seem to follow (though it remains to be proved) that overlap should be kept to a minimum, and therefore that a search-pattern using equally spaced fixations is the most efficient.

Another question about which unquestionably we need much more information is that of the effect of fixation-time on the parameters of the detectability-function. It is true that, left to themselves, searchers usually use fixations lasting 0.25 to 0.50 secs, but this does not mean that they could not be trained to alter this habit, or be subjected to an external pacemaker. If, for instance, as is often the case, there is an upper limit to the time allowed for the search, ought this time to be spent in fewer, longer fixations with a view to raising the value of p_0 (and possibly σ), or in more, shorter, fixations in order to improve the coverage? The

answer to this question will obviously depend on the relationship between the function connecting detection-expectancy with fixation density and that relating p_o to fixation time. The latter is presumably of the form shown in Fig. 7, but we have little or no knowledge of the range within which p_o rises from very low values to approach unity.

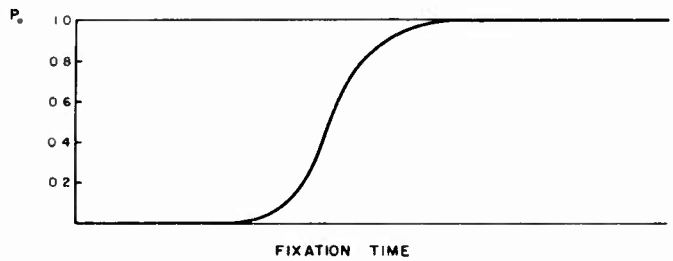

Fig. 7

Lastly I feel we should consider, more closely than we perhaps have done, the effect of boundary conditions. With search fields fairly small in extent relative to the inter-fixation distance, and relatively few fixations, the wastage of detection potential near the boundary can become commensurate with the effectively applied potential in the middle of the field. The choice of fixation-patterns which maximize search-efficiency needs to take this into account.

Although there is plenty still to be done along the lines I have mentioned, there remain other problems which we have heard discussed to some extent. They concern the question of what in the last resort decides whether an individual will see something he is looking for or not. There are strict psychophysical limits to what anyone *could* see. But who has not seen somebody look persistently but in vain for an object that is clearly visible to an onlooker? The problems which arise here are, to me at least, of even greater intrinsic interest and, probably, importance than those of the simple physical stimulus factors to which, at the present stage, we are bound to give much of our attention. At a future meeting of this kind, perhaps this direction of emphasis may be reversed.

ELLIS L. RABBEN: While this has been an excellent and a particularly revealing program, it would be unrealistic to expect an "answer" to the problems of visual search to be developed right here. I would suggest, however, that the most interesting question we might consider as a result of this symposium is this: what is the significance of the research that is underway in this field?

As a start toward answering this, we have to assume that the papers presented here do reflect the interests and efforts of serious scientists working in the field of visual search, and that the military viewpoints presented are, in truth, real and valid. What kind of fit therefore, is there between visual search problems as the military see them and the research that is being done to solve them?

First, it appears that almost all the work being done is laboratory work, and therefore to some degree it is unrealistic. This raises the problem of determining the validity of the laboratory studies to the real situation; since the problem was put in the laboratory in the first place to avoid the complexities of the real situation, this may not be easy. In this connection, I would like to recall the comment by Edwards to the effect that there is a real danger of so simplifying the problem to permit it to be handled more easily that it is not a problem any more. Now I insist on the scientific approach too, but I do not translate this to mean laboratory work only. I find myself in agreement with Blackwell's comment that we must deal with the inhomogeneities of the real world.

Similarly, another factor to consider in assessing the fit is that almost all the work reported is general, perhaps basic research. There seems to be a reversal here of the usual imbalance between basic and applied research in that it is almost all basic; surely this is no more desirable than the other way around.

Insofar as any research in vision can be expected to contribute eventually to solution of the basic puzzle, the kinds of work reported here are useful. But if these works are compared specifically to the needs as the military see them, and to the nature of the problem, the fit seems to be pretty poor. I suspect that we may be developing many ingenious solutions for which we will have to find problems.

Perhaps then we should say something more about the problems. Let us consider the needs of tactical visual reconnaissance as an example. For these needs, the papers at a meeting of this sort should result in at least four kinds of ideas about visual reconnaissance (although the same family of remarks would apply as well to air-to-air search, or air-to-sea, or whatever). These ideas are:

1. The place of visual observation in the family of reconnaissance sensing systems,

2. The effectiveness of visual reconnaissance,

3. Some visual reconnaissance problems for which research on vision should provide solutions, and

4. Directions which vision research should take to improve visual reconnaissance.

Now we know, from thinking developed outside of this symposium, that the place of visual observation in the family of reconnaissance sensing systems is assured by one outstanding virtue: speed. In a fluid situation, speed is the overriding consideration. Obviously if targets do not remain in one place very long, they must be acquired before they displace.

If we now examine the ability of sensory systems to work very quickly, it is obvious that any system that requires interpreters to examine processed pictorial imagery, as for example photography, is going to take appreciable amounts of time. Consequently it appears that we will have to continue to rely heavily on visual observation in years to come despite the advent of newer sensors.

When we examine what this most timely sensory system buys for us however, we see that in comparison to other systems visual observation is not nearly as effective. Visual searching can result in a great deal of information, but it is too selective. Consider what ground forces, for example, might need in the way of intelligence and targets.

Ground forces would like to find out at least three things about an enemy by aerial reconnaissance. These are:

1. Where is the enemy, and how are his forces disposed?
2. What kind of enemy force is it, what is its composition?
3. What is the enemy doing?

Now how are these questions answered by looking at enemy territory from the air? There are certain indicators or signatures from which these answers may be deduced with varying success; there is no sensory system which gives the answer directly. Therefore one measure of effectiveness of a sensory system is which and how many signatures are vulnerable to it.

The conditions under which these signatures must be observed are significant. For example, the signatures are hidden and camouflaged as much as possible in combat, since the troops would prefer to stay alive. In addition, since land operations presumably are undesirable until control of the air is achieved, most of the flagrant signatures such as movement can be expected to occur primarily at night. Also, the aircraft from which the observing is being done would like to go very high and very fast to cover the largest possible area and to reduce vulnerability.

What can visual observation do to satisfy this need? First, it is not particularly useful at night unless the enemy cooperates by showing lights, nor is it generally useful in bad weather. Combat experience as well as theory shows that observation for tactical ground targets must be carried out at moderate or low altitudes. The effect of speed on searching is not known explicitly, but logically it should be deleterious since there is less time to look at high speeds than at slow ones. And finally, visual reconnaissance spots items of interest most easily if they are moving in the open; concealed, stationary and camouflaged items usually escape detection unless the observer is persistent, flies low and slow, and spends much time on the search.

Simple passive countermeasures degrade visual reconnaissance severely. This is not surprising, since almost all camouflage techniques throughout history have been designed to foil the visual observer. The value of keeping still to foil a visual search is well known, as is concealment under vegetation, in shadows, or in a convenient pattern.

Objects moving in the open are another matter. Visual reconnaissance is exceptionally effective against such targets in clear daylight. At night or in bad weather however, other sensors may be better. Therefore since there may be other ways to detect activity when most of it takes place (at night and in bad weather) it seems even more important for visual reconnaissance to be able to bring back

information about the location, composition, and activity of the enemy in the daytime, when he is lying in wait for nightfall.

When visual reconnaissance capabilities are pitted against signatures therefore, it appears that only about 30 per cent of the significant signatures can be expected to be found. Moreover, when the constraints of night, bad weather, and the time available for searching from high-speed aircraft are considered, it can be estimated that this 30 per cent is seen perhaps only about 40 per cent of the time.

The signatures are not all equally important, nor is their relative significance constant. However, it is evident that when time is the major desideratum, visual reconnaissance provides a little bit of inflexibly selective information in a hurry.

With these things in mind, we might say that the major visual reconnaissance problems for which vision research should provide answers may be developed from the following interrelated questions:

1. How can the numbers and kinds of signatures sensed be increased?

2. Can aerial observers pierce camouflage and, if so, how?

3. What is the most effective search technique for specific situations of terrain, speed, and signatures?

4. What are the best slant ranges at which to perform visual reconnaissance, in qualitative and quantitative terms?

5. What techniques can an aerial observer use for rapid recognition of the significance of the signatures he sees?

There are at least two directions along which vision research should be pursued to solve these problems. The first of these is controlled field experiment, to begin to develop a body of reliable data in addition to the empirical experience of veteran aviators and laboratory studies. The second is to devise ways to adapt certain of the techniques used in photographic interpretation for employment in visual reconnaissance, to enhance the capability for the same kind of quick recognition of targets visually as is routine on photography. I offer an analogy and a bit of empiricism to point up the importance of this last.

For many years the emphasis in photographic reconnaissance was on development of better and better cameras, to provide improved imagery for the photo interpreter to examine. At the same time, while the art of interpreting was exceptionally effective it remained primitive, so that the fine imagery was wasted for lack of a systematic technique for extracting information from it in amounts consonant with its quality. Similarly, in visual search, it is not profitable to consider what the eye sees apart from the use that the brain makes of what is seen. The major need is for techniques and training procedures to exploit what can be seen, whatever it happens to be, rather than for ever finer delineations of the detection lobe.

In support of this, consider the experience with submarine crews. It takes about 6 months to train a new submarine lookout to "see" as well as experienced

crewman. How this increased search ability comes about is not known to the trainee or the trainer; apparently it is a natural consequence of experience and stress. Yet there is no evidence that during this 6 month period there is any change in measurable ocular refractive power. Moreover, when such a trained observer goes up in an aircraft he cannot see as many items of interest as a pilot can. Surely *these* are the kinds of significant problems with which we should concern ourselves; they are problems of vision in the large, rather than the more conveniently handled and easier projects concerned with eyeballs.

If we now ask ourselves if the bulk of the vision research being done, as reflected by the studies reported here, is really responsive to the needs of visual reconnaissance, or to the needs of visual observation as the military see it, I would have to suggest that the answer must be that it is not.

REFERENCE

1. Boynton, R. M., and Bush, W. R. Laboratory studies pertaining to visual reconnaissance. WADC Technical Report 55-304, Part 1 and 2 (Sept., 1955, April, 1957); Boynton, R. M., Elworth, C. and Palmer, R. M., Part 3 (April, 1958).

ADDENDUM

A question has been raised by one of the discussants concerning the differences in radial distribution of eye fixations between the study presented by Ford, White, and Lichtenstein(1, 2), and functions presented in several publications of the undersigned(3, 4, 5, 6). First, I would like to emphasize, that the important point to be derived from both studies is that coverage in search is *grossly* nonuniform. If uniformity is desired (and it is certainly not desirable in many instances), the natural search tendencies of observers must be modified by some technique.

Second, it is my belief that the two studies are to a large degree not comparable, mainly because, in the Ford, et al. study, an empty field was used, and in our studies, a highly complex display was employed. Rather, the Ford(1) study is best compared with one by Baker(7), which was conducted under much more similar test conditions.

Returning to the original question, it was suggested by a discussant that the reported results may, in some way, be related to the fixation of the head necessary in ophthalmograph testing. It should be noted that the same result regarding concentration of eye fixations on displays has been obtained in a performance study where no constraints were placed on the relatively large sample of observers(4). (A preliminary discussion regarding the manner in which this function arises has been presented in the literature(3).)

I believe that this writer would be the last one to suggest that the recommended optimal (9° diameter) size display be used in engineering design handbooks. It was only intended to be an attempt at establishing an order of magnitude. It is based on a specific task, on a specific display, (although the same functions were obtained using photointerpreters viewing aerial photographs) viewed by individuals not having prior training at the task. Essentially, a first approach to the problem is suggested, and it may be inferred that either extremely large or extremely small static displays are contraindicated.

Lastly, Doctor Boynton specifically requested information regarding accuracy of the technique (ophthalmograph) employed. Our data show reliability of $\pm 0.1°$ standard deviation, and in most instances validity of better than the required $\pm 0.25°$ standard deviation. The term "required" has been used with care because it is meant to emphasize the fact that the eye is apparently not able to place itself at the desired point with better accuracy. This may be determined by simply recording eye fixations while an observer looks back and forth between two fixed points. The accuracy of fixation is approximately $\pm 0.37°$ standard deviation in the vertical meridian. These figures are for a 5° eye movement. Because of this inaccuracy in placement of fixation, by the subject, and instrumental errors, great care must be employed in interpreting just what the subject had intended to view on a display at a given instant. As such we have generally avoided such analysis in all but the earliest studies of our program where such analyses were used to help us define the problem. This in no way invalidates the use of these types of data in many other ways.

In the measurements, validity is dependent upon at least four factors, i.e., the amount of tangential error allowed in calibration, the ability to stabilize the head (in time), the centration of the beam on the cornea, and extraneous vibration. The first aspect is readily determined, and the latter may be controlled. The second and third points proved to be our main problems.

April 27, 1959 — Jay M. Enoch

REFERENCES

1. Ford, A., White, C. T., and Lichtenstein, M. Analysis of eye movements during free search. *J. Opt. Soc. Amer.*, 1959, **49**, 287-292.
2. White, C. T. Symposium on Visual Search Techniques, 7-8 April 1959.
3. Fry, G. A., and Enoch, J. M. Fourth interim technical report, Human factors in photointerpretation. Columbus, Ohio: Mapping and Charting Res. Lab., Ohio State Univer., 1957.
4. Enoch, J. M. The effect on visual search of the degree of generality of instructions to the photointerpreter. Columbus, Ohio: Mapping and Charting Res. Lab., Tech. Paper No. 696-14-270. Ohio State Univer., 1958.
5. Enoch, J. Effect of the size of a complex display upon visual search. *J. Opt. Soc. Amer.*, 1959, **49**, 280-286.
6. Enoch, J. M. Symposium on Visual Search Techniques, 7-8 April 1959.
7. Baker, C. H. Attention to displays during a vigilance task, I. Biasing attention. Cambridge, England: Med. Res. Council, Appl. Psychol. Unit Rep., APU 294/58, 1958.

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