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FACTORS UNDERLYING VISUAL SEARCH PERFORMANCE

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Contents

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INTRODUCTION

Visual search may be regarded as a special case of image evaluation. In this case the image may be a primary one in real object space and time or it may be derived from some secondary or intermediate imagery or display in real time or with time either compressed or expanded or, as in the case of a photographic display, frozen. Before image evaluation can occur, it is necessary that the object be detected, that is, it must be sufficiently different from the background in which it is embedded so that the observer becomes aware of its presence. The needed differences between object and background may be based upon luminance contrast, color contrast, size, shape, texture, movement, and temporal characteristics.

Sometimes, although rarely, we may be interested only in the detection of presence of the object, as in the case of searching for an aircraft against the clear sky at very high altitude. In this instance, the detection of any object at all is likely to be sufficient for our needs, since it is almost certainly an aircraft, almost certainly not a bicycle. Clearly, in this example simple detection is equated with successful search, and the image does not need to be evaluated because it has, in a sense, been pre-processed before the search task was undertaken. While most search problems are much more complicated, it may be said that the example just given is a limiting case, since before any higher-order discriminations and decisions may be made, detection must obviously have occurred.

Most search problems involve one or more discriminations of a higher order than does the one just mentioned. An example of the most complicated search task may be found in the case of low-altitude reconnaissance for military targets, where the problem is complicated by properties of the terrain, or "ground clutter", by the fact that the targets may be partially hidden or camouflaged, and by the presence of decoys. All objects in the field of view may be easily detectable, but the observer must evaluate his visual images in terms of extremely subtle differences. There are all degrees of complexity between these extremes.

It is clear that search depends, therefore, not only upon man's ability to detect objects, but also upon some act of information rejection. To identify an aircraft against the sky is, in this sense, simple. To commit a weapon with the required confidence that the target is military rather than civilian, real rather than a decoy, or hostile rather than friendly, is not simple. The images, whether directly received or provided by optical and electronic intermediary devices, must be evaluated in increasingly subtle ways. In this paper I would like to discuss some of the underlying factors in the search process which both facilitate and limit man's capability to evaluate his images. The factors in question are of three general sorts:

I. The properties of the human visual system

II. The properties of the objects and their backgrounds

III. The properties of the environment

Within each of these categories we will find both static and dynamic factors.

THE HUMAN VISUAL SYSTEM

It is neither necessary nor possible to give a detailed description of the visual system to this group and in the time available. I should like, instead, to emphasize certain factors which are directly related to search, with the understanding that nearly any aspect of the visual process may have some bearing on the problem. Also, as we shall see, much is known about the simpler kinds of search activity, so that it may be possible to find some causal relationships between the capabilities of the system and the performance of the task. Finally, because of the structure of today's program, I will not attempt to discuss those aspects of the visual process which are likely to be presented in greater detail and much more competently by Dr. Gould and Mr. Bloomfield. In order to bring us all to a common level of understanding, and in the interest of facilitating communication, we must first recognize certain facts about the structure and function of the visual apparatus.

Gross Anatomy

The whole visual system properly includes not only the eyes, the neural pathways, the cortex, and the musculature which causes the eyes to move, but also a number of very subtle feedback loops and movements of the head and body. In the simplistic treatment of the system made here, however, we are only concerned with details in the case of the structure and sensitivity of the retina and in the optical and muscular dynamics of the inside and the outside of the eyes themselves.

THE GLOBE

Figure 1 schematically shows the principal parts of one eye. It is an extremely compact optical device, which by some very sophisticated methods of coding, enables one to discriminate light, shape, size, color, distance, movement, and other properties of objects in the external world. All this it is able to do over a tremendous range of ambient conditions, and through the use of an attached power supply which keeps it operating for around 70 years in the typical case. Most humans come equipped with two of these devices, which not only implies a spare but actually enables certain operations which would be impossible

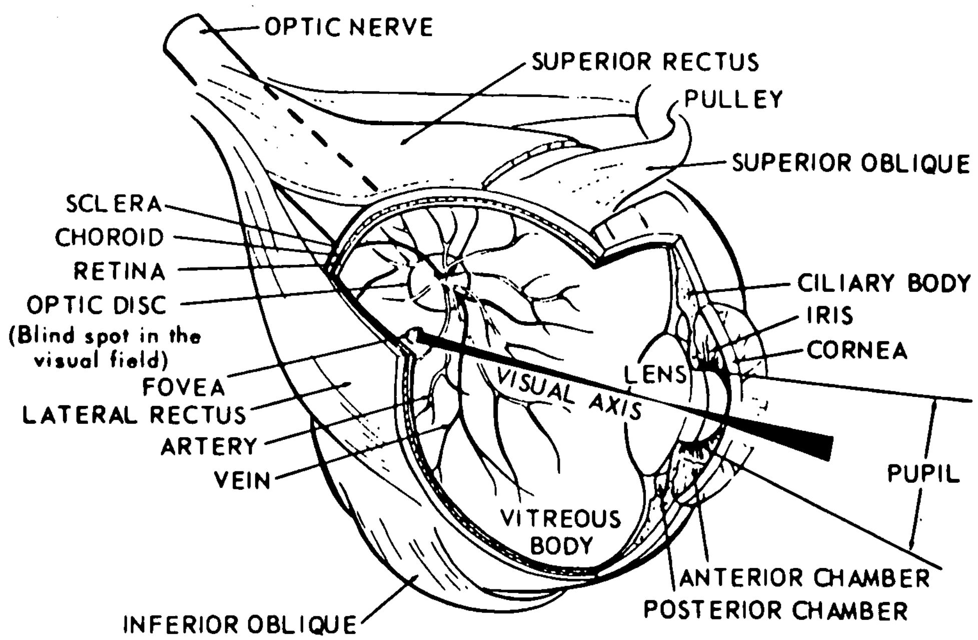

Fig. 1. Schematic cutaway drawing of the right eye, showing the extraocular musculature and the essentials of the optical system. (From Webb, P. (ed.) **Bioastronautics Data Book**. NASA Publication SP-3006, 1964).

with only one. The production problems have been solved so well that we are currently in peril of overproduction.

Light from the object first impinges on the cornea, where it is refracted owing to the higher refractive index of the curved corneal surface. It passes through the adjustable iris, or pupil, and is further refracted by the lens, so that, in a perfect eye, the image is sharply focussed on the retina, provided that the combined power of the lens and cornea are appropriate to the object distance and that the iris is not so small that diffraction effects become severe nor so large that the spherical aberration of the system becomes a problem.

THE RETINA

The retina is a highly specialized structure, as may be seen in Figure 2. For our purposes we shall consider only the layer which contains the actual photoreceptors which convert light into neural signals which are appropriately encoded and transmitted along the optical pathways to the brain. The photoreceptors are, in man, of two general types, usually called rods and cones. The cones, in turn, are almost certainly of three types, at the very least, with different but overlapping spectral sensitivities which enable the appreciation of color. The cones are most abundant in the retinal region centered around the visual axis, and in the immediate area of the fixation point there is a part of the retina known as the fovea, where rods are completely absent, the cones are elongated and closely packed, and where the other layers of the retina are suppressed and there is no interfering vascular tree. For these reasons the fovea is the part of the retina which enjoys the best color vision and the best visual acuity. Outward from the fovea, as may be seen in Figure 3, the number of cones per unit of area diminishes rapidly, while the density of the rods increases to a maximum and then falls again toward the edges of the visual field. Each of these two kinds of receptors has its own area of specialization. The cones are good for the appreciation of fine

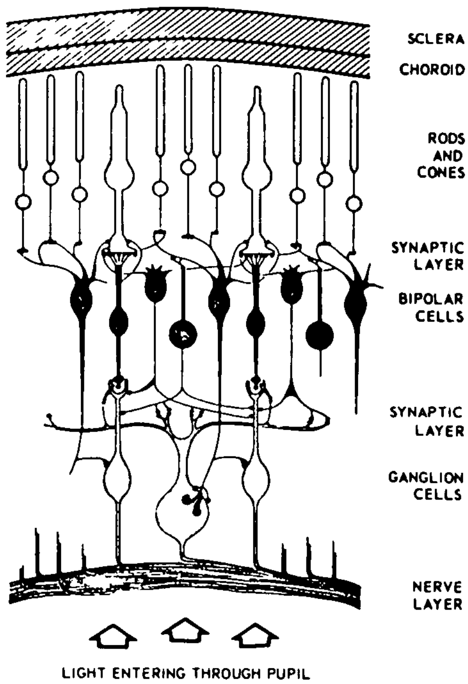

Fig 2. Highly schematized drawing of the elements of the human retina. (From Webb, P., op. cit.)

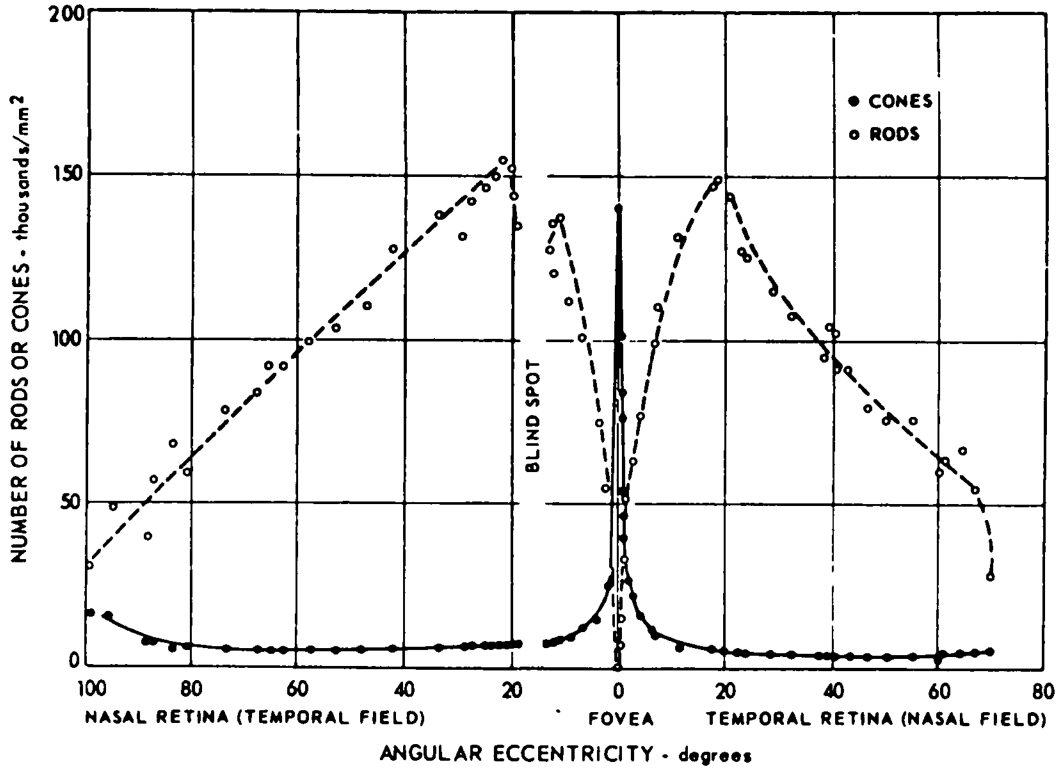

Fig 3. Distribution of the rods and cones across the human retina in the horizontal meridian. (Data from Osterberg, G., Topography of the layer of rods and cones. Acta Ophthal., 13, Supp. 6, 1935)

detail in the region of the fovea, and for the discrimination of color On the other hand they are capable of functioning only at relatively high levels of luminance (10^{-3} ft L and above), so that both visual acuity and color vision are severely disabled when night-time conditions prevail Furthermore, because the cones are concentrated near the foveal center, both visual acuity and color discrimination are reduced as the peripheral field is approached

The rods, on the other hand, are specialists in low-level operations, being capable of useful work down to levels of about 10^{-6} ft-L Although the retina as a whole contains a great many more rods than cones (125 million rods, 7 million cones), because of the manner of their connection to the optic nerve and the relatively huge solid angle involved, visual acuity in the rod-rich portions of the fovea is relatively poor, and no color vision is possible

MUSCULAR MECHANISMS

There are muscle systems both inside and outside of the eyes, and although it is obvious that the extrinsic muscles which cause the eyes to move about during the search process are of great importance, the systems within the globe are too The intrinsic muscle systems in man are of two sorts, the ciliary muscle, which causes the shape of the lens to change and thus to adjust the focus of the eye to near and far objects, and the muscles of the iris which by opening or closing the pupil, exert some control over the amount of light reaching the retina The two inner systems react upon each other and with the extraocular muscle system as well For example, when the two eyes are moved so as to converge the two optic axes upon a nearby object there is an accompanying relaxation of the ciliary muscle which thickens the lens and a concomitant diminution of the size of the pupillary aperture

Visual Fields

At any instant in time the effective visual field for two eyes is as shown in Figure 4 The outer limits of the field of view are set by the shape and optical properties of the eye and by the way in which the eye

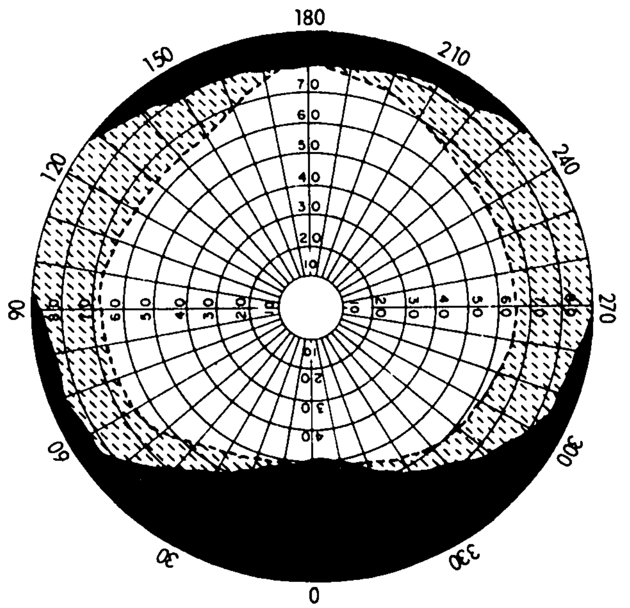

Fig. 4 Limits of the binocular visual field. (From Webb, P., op. cit.)

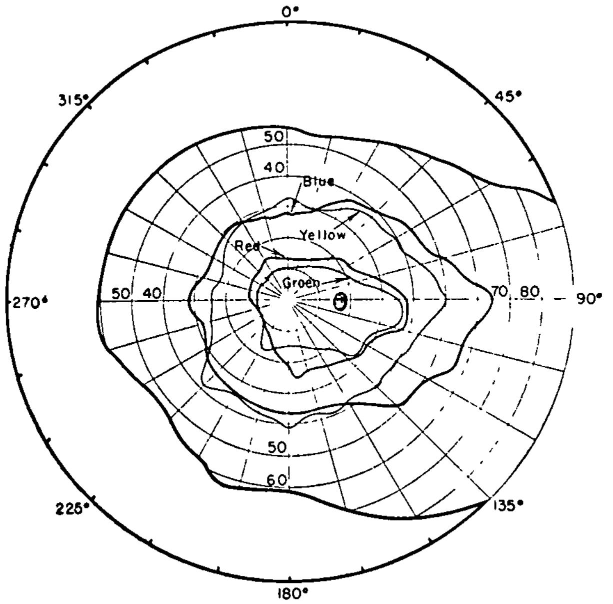

Fig. 5. The field of view of the right eye, showing the limits of color discrimination for some colors. These will change, however, with changes in luminance and size of the test patch. (From Boring, E.G. et al. **Foundations of Psychology**, Wiley, New York, 1948).

is mounted in the head. This figure, however, suggests the absolute functional geometric limit of the static case; as we have already indicated, there are significant local variations in visual function. One example has been given, that of color discrimination, and Figure 5 shows the outer angular limits which have been found by experiment for some representative colors. That acuity falls off with increasing distance is well known, and in Figure 6 is shown the general form of that relationship, for the high-luminance case.

It is obvious that best vision, at high and moderate luminance levels occurs at the center of the visual field. The human observer, having detected an object of possible interest in the peripheral retinal image, responds almost automatically by redirecting his eyes so that the image is swept into the region of the two foveas. At very low luminance levels, conversely, he is well advised to avert his gaze so as to put the image on the rod-rich part of the retinas, although this is, for untrained observers at least, a response which must be learned.

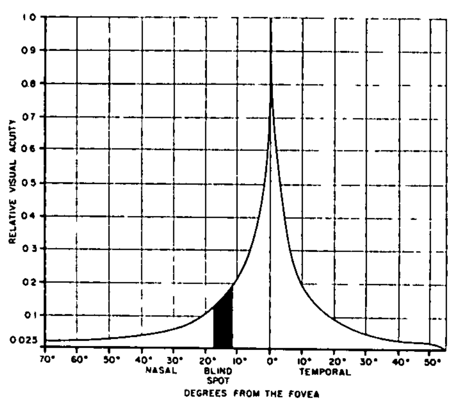

Fig. 6. Visual acuity at different retinal positions for high adapting luminance. (After Wertheim, T., Uber die indirekte Sehscharfe. Zeit. Psychol., **7**, 172-187, (1894).

Eye Movements

The extraocular muscles permit eye movements in the usual sense. The movements may be voluntary, in which case their goal is to search and scan the visual field and then to position the image most advantageously. These voluntary movements may be angularly large and coupled with head and body movements, as in the search process, through to very small angles, on the order of a few minutes of arc, when they serve to maintain fixation once the object has been located. Other eye movements are quite involuntary, and in the normal case small and rapid. It is this sort of movement which we now believe to be essential for the visual process, for when they are experimentally damped out vision is seriously interfered with. For our purposes, however, we will consider only coordinated binocular eye movements, performed under voluntary control, and mediated by the extraocular muscle system.

Visual Function

Before proceeding to some of the experimental findings regarding the actual search process, it is instructive to review certain aspects of visual function which underly it. A tremendous amount of work has been done in the past century on the basic variables of the visual stimulus which affect seeing, and, indeed, the foundations of what is now known as visual science were laid in the mid-nineteenth century by the two German intellectual giants Helmholtz and Fechner. Although the methods of experimentation have become ever more elaborate and quantitative, the basic objectives of psychophysics remains the same, to relate physical properties of the stimulus to the sensory effects they produce. In the visual realm the properties of the stimulus which are of greatest concern are its size, its luminance and chromatic contrasts against its background, its shape, its duration, and the rate and extent of any relative motion involved. Since much of the best recent data have come from experiments in which luminance contrast has been the dependent variable, it is well at this point to define contrast as we will be using the term. In the simple case of a uniformly luminous stimulus seen on a uniformly luminous background, the contrast is defined as the difference between the luminance of the stimulus, B_t, and the luminance of the background, B_o divided by the luminance of the background. Thus,

$$C = \frac{B_t - B_o}{B_o} \quad ; \text{ or } \quad C = \frac{\Delta B}{B_o}$$

This, incidentally, is a somewhat different definition of contrast from that used by photographers and others, and in visual science there is a good reason for its use. It can be seen that stimuli lighter than the background can vary in contrast between zero and infinity, and that stimuli darker than the background can vary between zero and minus one. It has been found in a number of studies, notably those done at the Tiffany Foundation and reported in 1946, by Blackwell (1), that over a wide range of conditions positive and negative contrast stimuli of the same numerical value are about equally detectable, irrespective of sign. (This relationship does not hold for large stimuli at very low luminances.) A useful simplifying finding, reported by Macadam in 1949(6), has been that color differences are relatively unimportant in the case of visual *detection* if the luminance differences are sufficient. This is not to say that color is not important for many visual discriminations, just that initial detection of a stimulus seems generally to be based upon luminance differences; only when these become small does color help in the detection process.

The two findings mentioned above have had, for better or worse, a far-reaching effect on the conduct of research on visual detection in the United States. They suggest, obviously, that one can most efficiently study the detection process by working with achromatic (or more properly, polychromatic) targets which are brighter than their also achromatic backgrounds. In view of the tremendous number of experiments which need to be done in order properly to investigate the influence of size, duration, background luminance, position in the field, and so on, experimenters have been glad enough to be freed from the additional permuting parameters of color and contrast sign. Much of the data which I shall present will, of necessity, relate to the detection process, since it is the process which has been most exhaustively investigated and because detection is generally agreed to be the simplest kind of visual discrimination – the forerunner of higher-order processes such as recognition, identification, and, ultimately, decision-making. During the past few months an effort has been made to bring together the best available data regarding visual detection, from several laboratories, in hopes of emerging with a highly consistent and usefully quantitative set of tables and curves which represent our best current information (4). Most of the data used are thorough, systematic, and statistically elegant. In a few cases, they are, to paraphrase E. O. Hulburt, the result of interpolation, extrapolation, and exasperation. I do not believe, however, that we have knowingly done violence to the facts.

CONTRAST DISCRIMINATION

The data of contrast discrimination refer to the very simple case of uniform circular stimuli seen against extended, uniformly luminous backgrounds. The location of the stimulus is, in this case, known exactly, as is its time of occurrence. Thus, the data may be said to represent the zero-probability case in the context of visual search. This does not mean, however, that the data cannot be applied to the problem of search, to the case of non-circular objects, or non-uniform objects and backgrounds, or to moving stimuli. There are techniques for making these conversions, but with quite variable degrees of confidence. In complicated situations it is generally much safer to perform specific experiments rather than to attempt to convert the data from these simple situations. (I will not dwell upon this point now, but I hope that opportunity will arise during the symposium for some discussion of the whole problem of so-called "field-factors".)

The first set of data comes from experiments in which viewing time was essentially unlimited, and the observers were allowed to use whatever part of their visual field they found most advantageous, that is, fixation was uncontrolled. These data, which are shown in Figure 7 actually come from two studies, separated by a continent in space and nearly two decades in time, but with essentially identical psychometric methods and similar populations of observers. The basic data come from the Tiffany studies already alluded to, and represent approximately 90 000 observations in the range of target sizes between 0.6 min to 6 degrees of arc. Additional data from the Visibility Laboratory (11, 12) have extended the data to very large stimuli, and are based upon a total of 21 000 observations. The values of threshold contrast indicated are those required for 50% detection. The same data have been replotted in Figure 8 and here may be seen the discontinuities which correspond to the functional shift from cone to rod receptor populations as the background luminance is reduced.

Clearly, in practical search situations inspection of the stimulus is not of unlimited duration. The eyes tend constantly to move, and as we shall see later, the average duration of a single fixation is about one-third of a second. Exhaustive studies have been made of the effect of exposure time, but in the context of visual search, the 0.33 sec case is of greatest interest in most instances. The data from such studies are shown in Figure 9. In this case, the object lies at the foveal center. The figure and its companion ones for different exposure times* manage to combine data from eight experiments and represents a total of 436 000 observations by a total of 33 observers.

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* Data for exposure times of 1, 1/2, 1/5, 1/10, 1/30, 1/100, 1/300, and 1/1000 second have been plotted in the report by Blackwell and Taylor (4), just now being published.

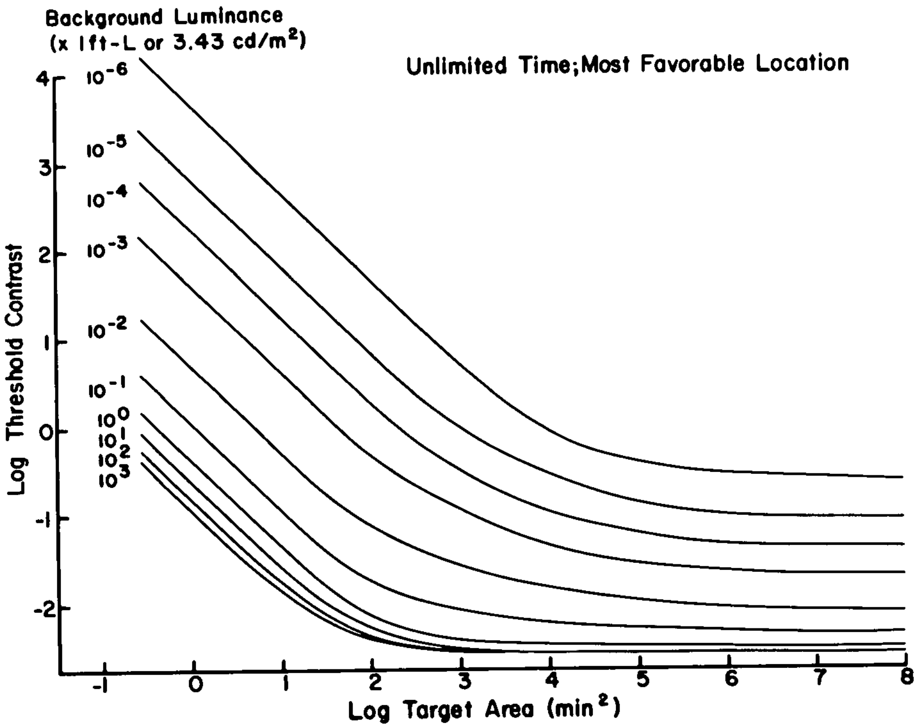

Fig. 7. The threshold contrast for targets of varying size and at background luminances from 10^{-6} ft-L up to 10^3 ft-L (Ref. 4)

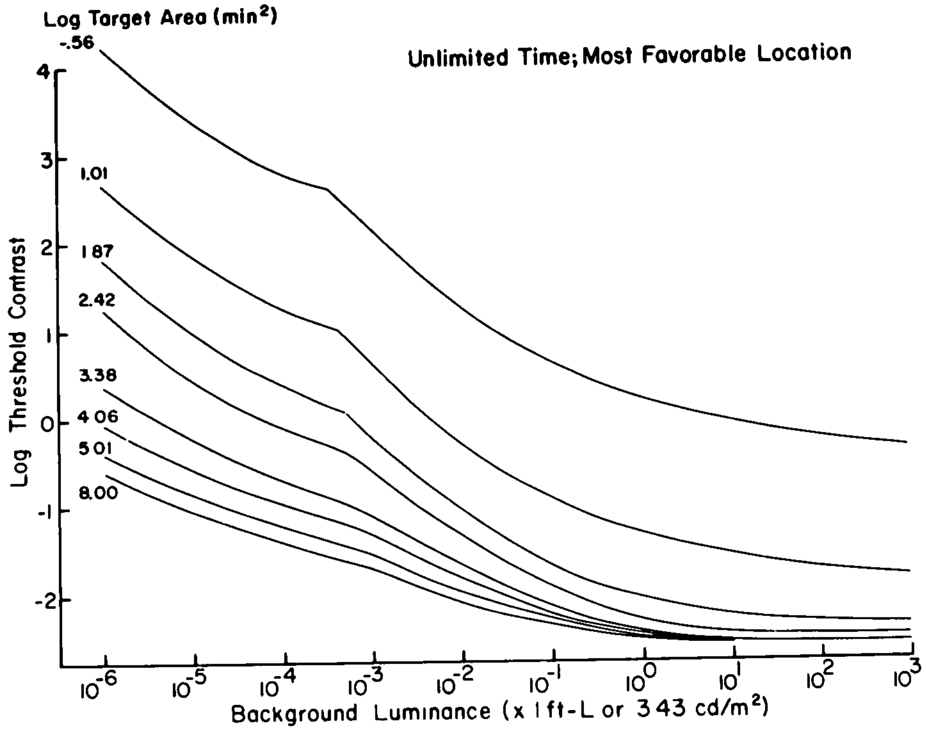

Fig. 8. The data of the previous figure replotted to show the transition from rod to cone vision at about 10^{-3} ft-L (Ref. 4).

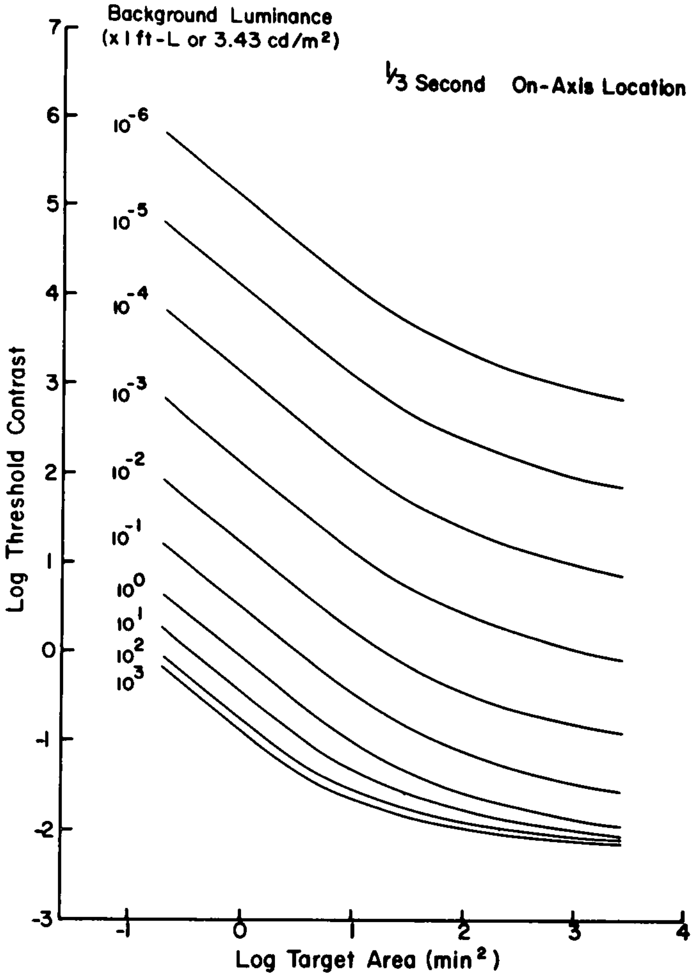

Fig. 9. Threshold contrast for circular targets of 0 33 sec. duration as a function of target area for various adapting luminances. (Ref. 4).

Off-axis viewing is much less well known, and is currently under study at our Laboratory and elsewhere Only four studies will be reviewed here The first of these was done by Blackwell and Moldauer (3) and was limited to the case of point-source (1 arc minute) exposed against various background luminances for 1/100 second The data, representing 368 250 observations by two observers are shown in Figure 10

A recent study by Taylor (13) conducted at high luminance and with a constant exposure time of 1/3 second, showed the effect of varying target size at various locations in the near periphery, i e , out to 12 5° The data are shown in Figure 11, and to the degree that search is conducted at daytime levels and within the central 15° cone, these data are probably most germane to the search situation Approximately 768 000 observations by four observers are represented Another study, by Blackwell and Markert (2) is entirely analogous, although they used exposures of 1/100 second and a lower background luminance As may be seen in Figure 12, there is a two to three log cycle increase in required contrast and a not unexpected change in the shape of the curves (3 observers, 35, 350 observations) Most recently we have studied (10) the special case of detection of targets of varying size exposed for 1/3 second and centered on a point 20° away from the visual axis on the horizontal meridian These data are shown in Figure 13

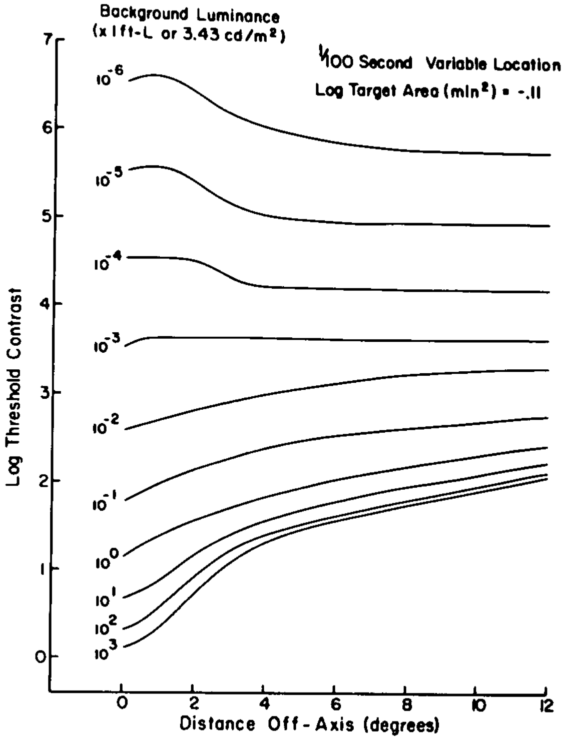

Fig. 10. Threshold contrast for brief flashes of small targets. (Ref. 4).

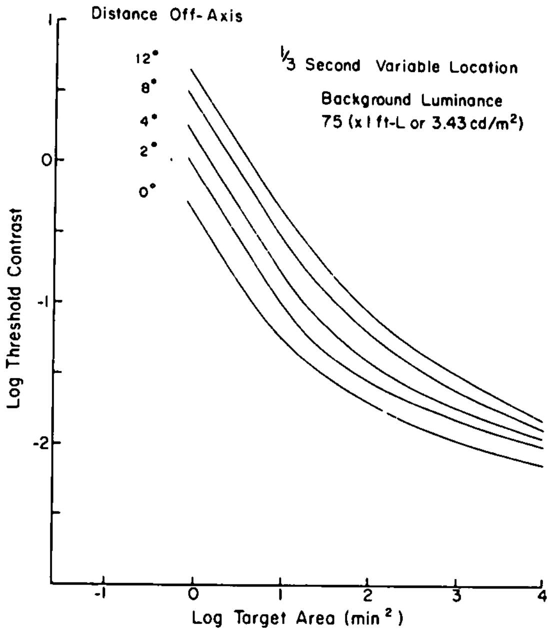

Fig. 11. Threshold contrast as a function of area for 0.33 sec. flashes presented to various parts of the visual field. (Ref. 4).

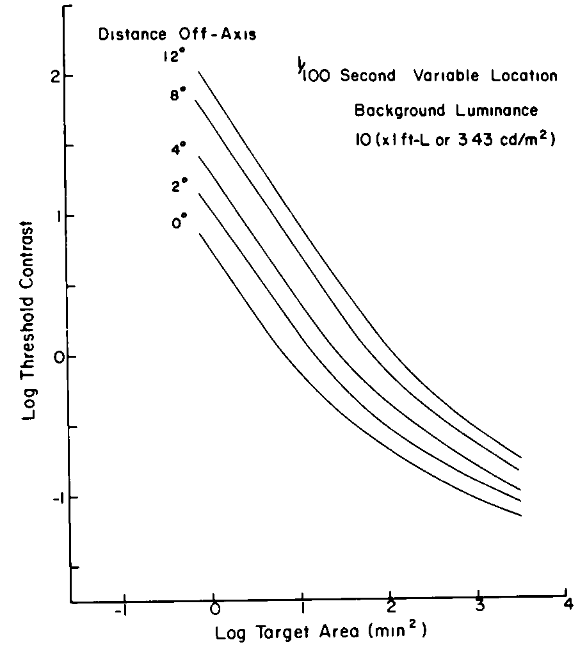

Fig. 12. Threshold contrast in various parts of the visual field for 0.01 sec. flashes as a function of target size. (Ref. 4).

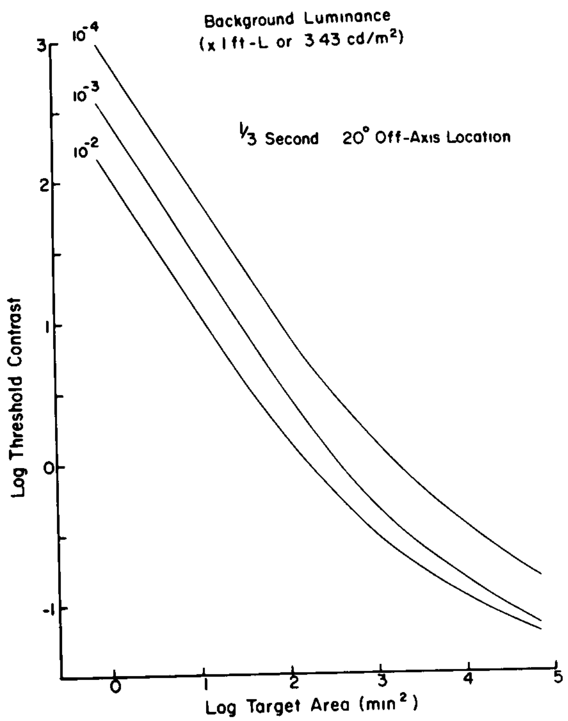

Fig. 13. Threshold contrast at three adapting luminances for targets of 0.33 sec. duration presented 20° from the fovea as a function of target area. (Ref. 4)

The data of the foregoing Figures, it will be recalled, refer to very simple stimuli and backgrounds, with location, time and size known exactly, and limited to colorless targets. In the studies where stimulus location was varied, azimuthal differences in sensitivity were found. The pattern of these differences, however, appears to vary between individual observers and even between conditions for the same observer and I do not believe that we yet have enough data to make sense of this seemingly capricious effect. Finally, it must be emphasized that the detection data are of limited but definite value in the prediction of search probabilities. They are appropriate to the case of initial target acquisition under the simplest of stimulus conditions only, and may be applied to more complex circumstances in many, but by no means all cases of concern.

Search in Real Situations

Two avenues are open to the investigator interested in actual problems of search. He may use the materials and conditions of the real environment, either by field trials or by simulations, or he may try to abstract those features of the task which he believes to be important and then perform laboratory studies in which these parameters are examined. The former class of study tends to be expensive and time-consuming, and the results obtained can very rarely be generalized to other problems. The latter class is generally productive of data which may give insights into the operational importance of the parameters studied, but which may or may not be generalizable to other conditions. In the context of this symposium it is proper to review at least a few studies of the second type. The examples I have chosen are not intended to be definitive ones, but they illustrate possible modes of experimental attack, and have resulted in data which clearly point up the importance of some of the variables which influence the search process.

OCULOMOTOR ACTIVITY

A study by White and Ford (15) of simulated radar search measured eye movements by electro-oculographic means. The background was a 30° circular field without luminance gradients, and a single target was used. The target could appear anywhere in the field, and five seconds were allowed for search. The results give some important insights into the use of the eyes in this sort of problem. Figure 14 shows

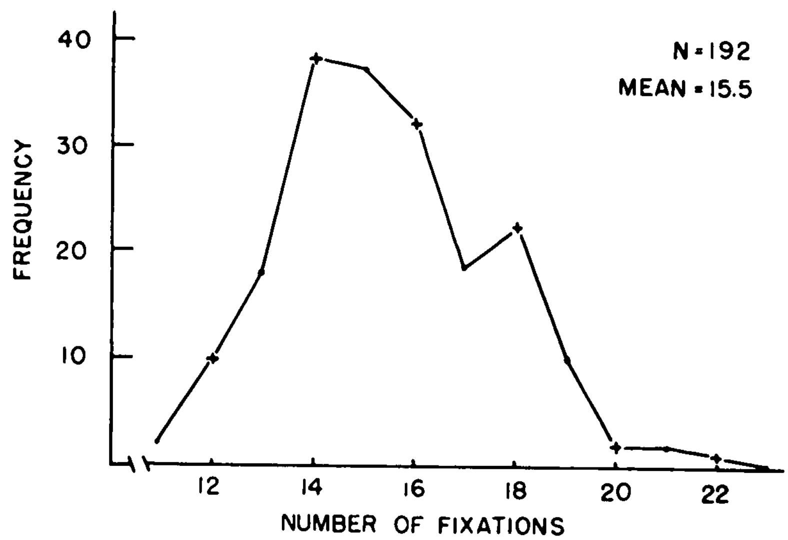

Fig. 14. The frequency with which various numbers of fixations were observed during five seconds' search of a 30° circular field. (Ref. 15).

the frequency distribution of the number of fixations made during the 5-second period Note that the average fixation rate is 3 1 per second The dwell times were distributed as shown in Figure 15 with their mean value at 0 28 second The average excursion length of the eyes is shown in Figure 16 For this special case (30° unstructured field, free search) the average eye movement sweep amounted to 8 6 degrees of arc Another finding in this study, but not shown in a figure, was that the fixations were largely made in an annulus about halfway between the center and the edge of the field In all the data there were appreciable individual differences in the searching process

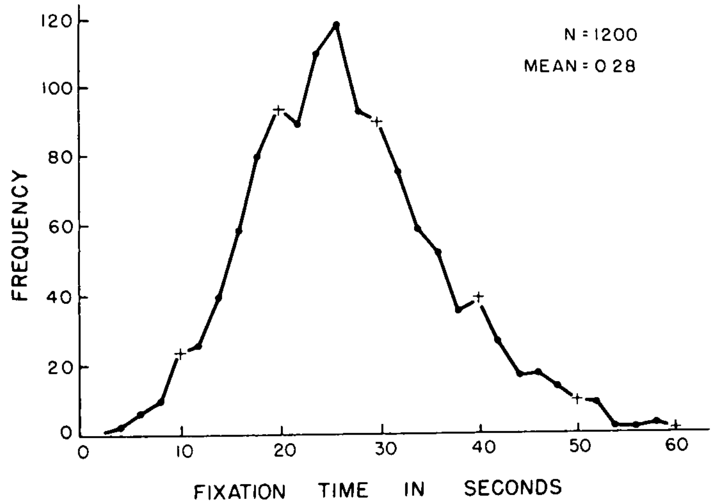

Fig. 15 Frequency distribution of fixation times. (Ref. 15).

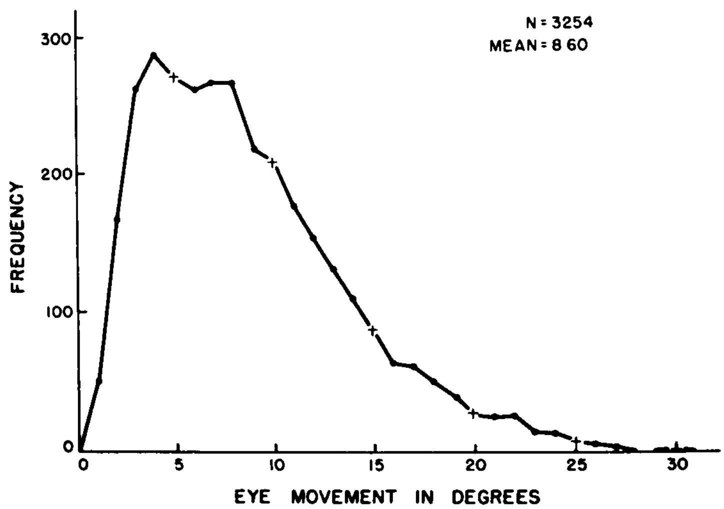

Fig. 16 Frequency distribution of observed eye movement extent in the study by White and Ford. (Ref. 15)

SEARCH IN STRUCTURED FIELDS

A number of laboratory studies have been made in which the complexity of the background was a variable, and against this variable have been permuted such things as target size and shape, color, and the use of cues Of these many experiments we shall have time to mention only a few S W Smith (9) has worked extensively on the time required for search in complex abstract visual displays, and some of his results are well worth noting The area to be searched was a 20° circle with luminance 7 4 ft-L Within this area he placed a variable number of brighter pseudotargets (Contrast = +1 65 initially, but later reduced to study the contrast effect) which consisted of small circles subtending from 6 to 9 minutes of arc The number of pseudotargets was varied from zero to 1024 The real targets were triangles, squares, pentagons, and hexagons of the same area and contrast as the pseudotargets The results of varying the number of pseudotargets is shown in Figure 17, which possibly contains no surprises, but which nicely corroborates the results found by other investigators Target shapes most similar to the circular pseudotargets were less easily found, as is shown in Figure 18 When the contrast of the circular pseudo-targets is reduced or when they are made smaller than the real target, the relationship apparently becomes curvilinear The effect of changing both contrast and size is shown in Figure 19 Smith suggests, and I agree, that targets which differ only in shape from the pseudotargets must be fixated foveally before they may be successfully discriminated, owing to the poor visual acuity in the peripheral field Targets which differ in size and/or contrast, however can be differentiated further out in the periphery

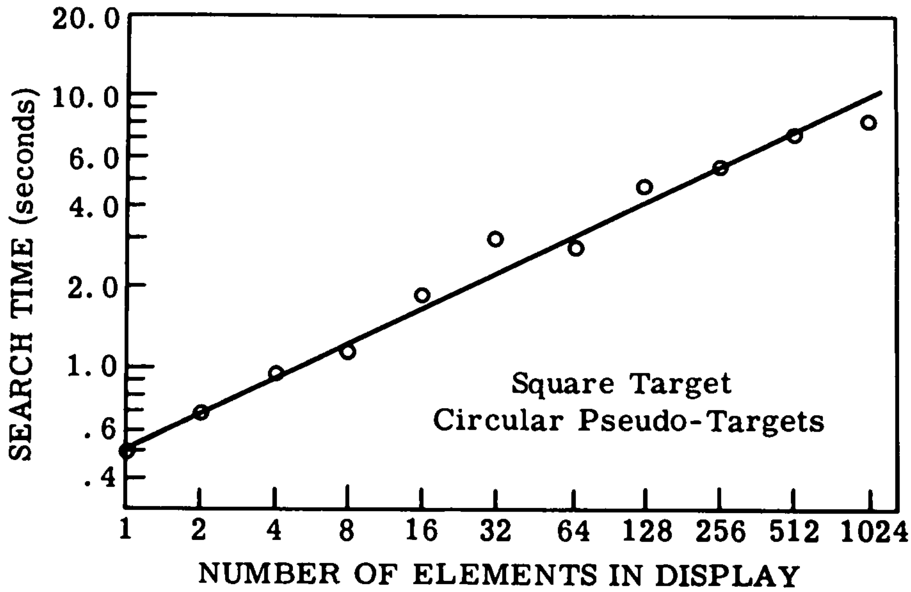

Fig. 17 Search time as a function of number of elements in display. Geometric means of four observers' median search times. Pseudo-targets same size and contrast as target.

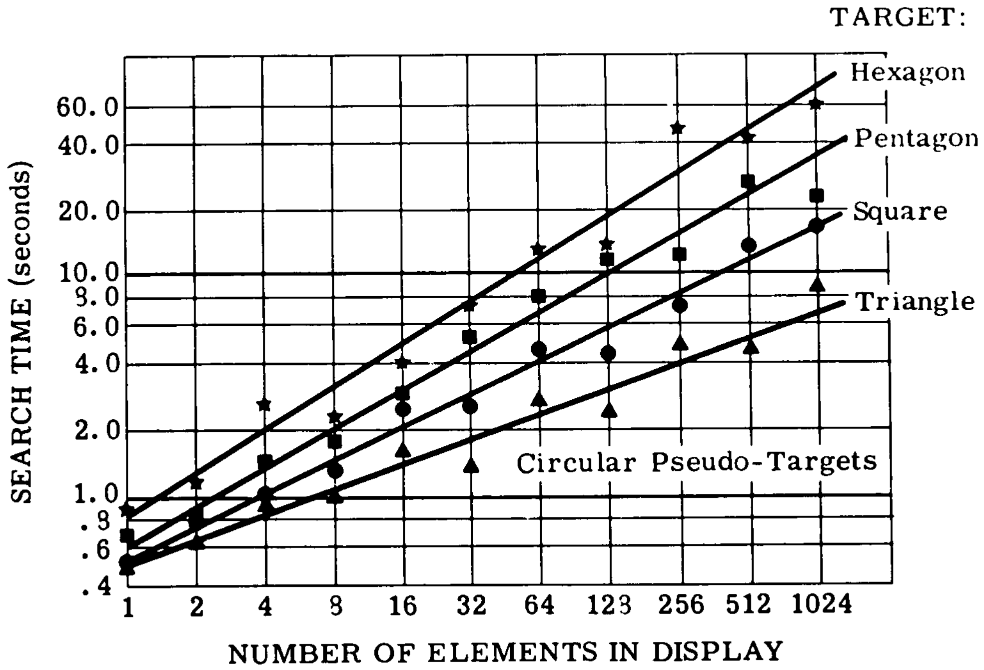

Fig. 18. Search time as a function of number of pseudo-targets for several target shapes. (Ref. 9).

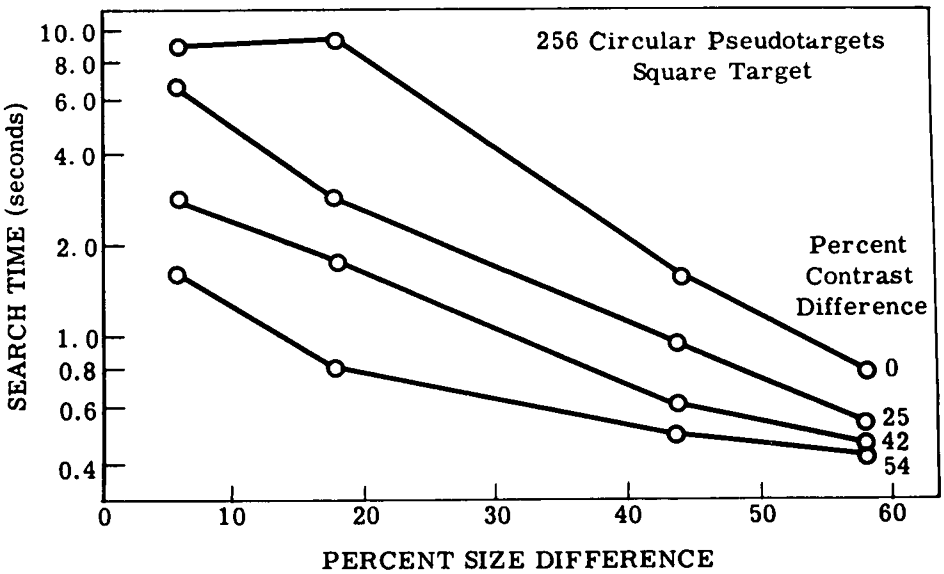

Fig. 19. Search time as a function of size and contrast difference between targets and pseudo-targets. (Ref. 9)

CUES

Most search situations are characterized by the presence of some sort of cues in the background. One looks for vehicles on roads, for ships on rivers or, at sea, at the head of the wake. Smith refers to a study in which the number and variety of cues were used as a variable. Figure 20 shows an array containing 512 pseudotargets, one real target, and a cue, which is the rectangle, which happens to be very near the target. Clearly, in this simple case the search time is very much reduced. In Figure 21 there are 16 cue symbols, all of the same type. Again, we might expect search time to be reduced, but we have a feeling that if there were very many more cue symbols in the display this advantage might vanish. Figure 22 also contains 16 cue symbols but of four different types. If the observer is told that the target is located near one of the cues, search time is reduced. The data from this study are shown in Figure 23, which largely confirms our suspicions about the action of cues in regard to their numbers, but likewise shows the rather interesting result that displays containing several different kinds of cues required longer search times than those with an equal number of identical cues.

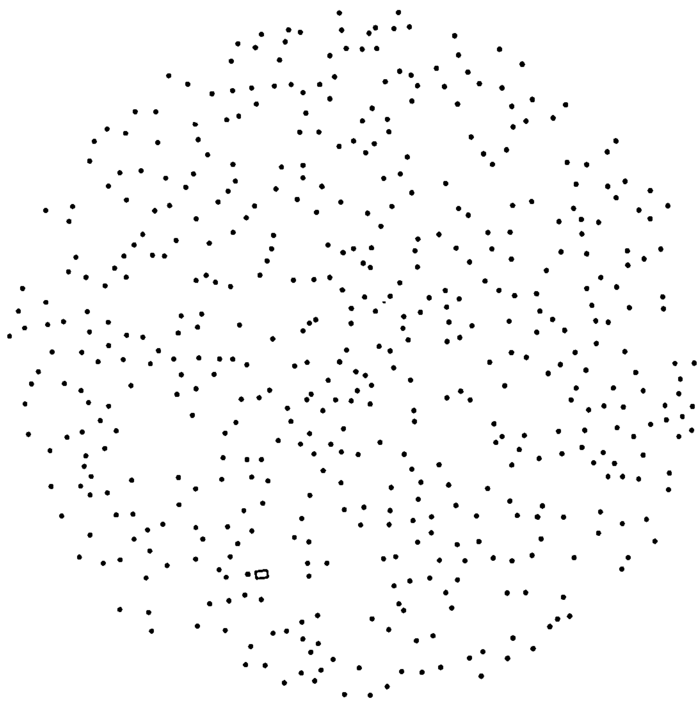

Fig. 20. Display with one rectangular cue symbol. (Ref. 9).

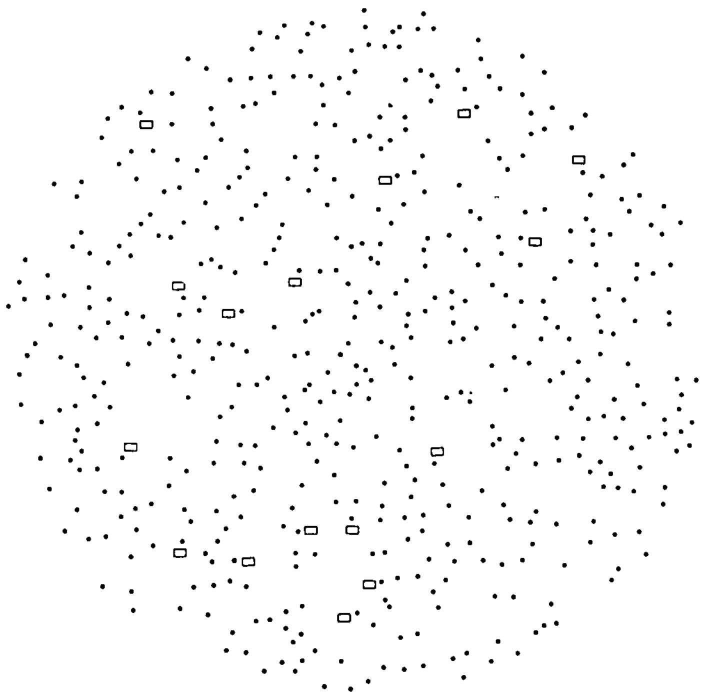

Fig. 21. Display with 16 cue symbols of the same type. (Ref. 9).

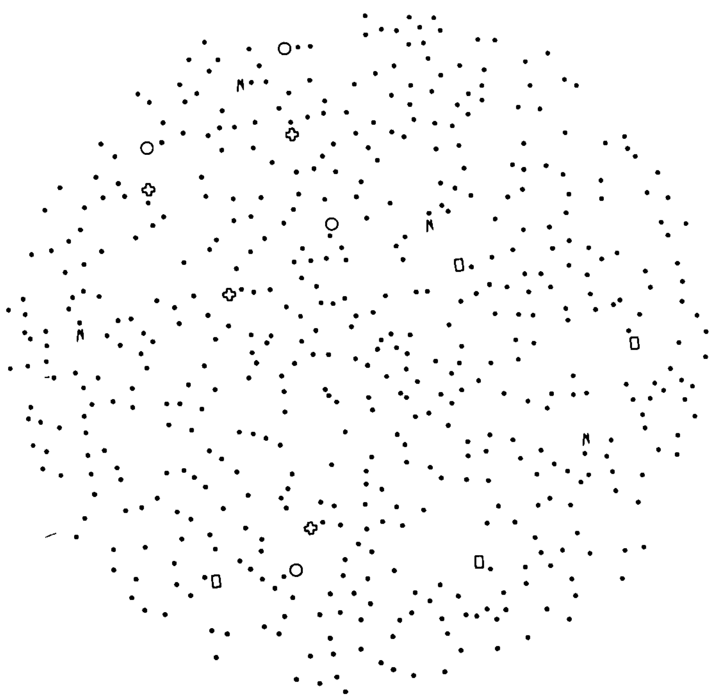

Fig. 22. Display with 16 cue symbols of four different types. (Ref. 9).

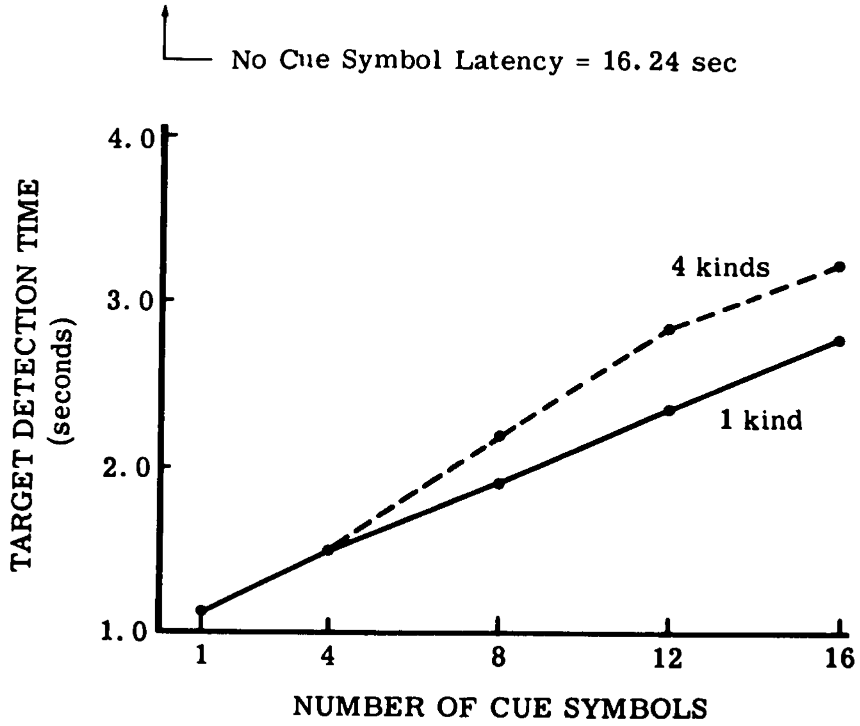

Fig. 23. Search time as a function of number of cue symbols and the number of symbol types. (Ref. 9).

A somewhat related study by Shontz et al. (8) investigated search in a map-reading problem. Color cues were used to improve search time on standard aeronautical charts and upon achromatized ones. The cues were small colored circles attached to the charts close to the checkpoints of interest. The colors were chosen for their good discriminability in the near periphery. Their results are shown, in part, in Figure 24. It is evident that the use of color cues is advantageous in this task, and that somewhat more gain is to be had by using achromatic backgrounds.

Linear cues, analogous to roads and rivers, have been studied by Erickson (5) who used displays like those shown in Figure 25. The pseudotargets were simple circles, and the real target was a broken circle like the well-known Landolt ring. The results are shown in Figure 26 where it may be seen that the linear cue effects a significant reduction in search time, and also that the advantage is relatively greater as the number of pseudotargets becomes greater.

Finally, we are interested in the influence of the size of the area which must be searched. For some data relating to this problem, I have borrowed Figure 27 from an extensive study by Krendel and Wodinsky (6). Search time appears to be a linear function of the area which must be searched. The upper curve is for the time of detection of 75% of the targets while the lower one shows the median times to target detection.

This rather cursory review of some of the experimental approaches to studying the effects of various factors inherent in the target-background complex should not be taken to be definitive. Many other investigators have done, and continue to do, experiments in this area.

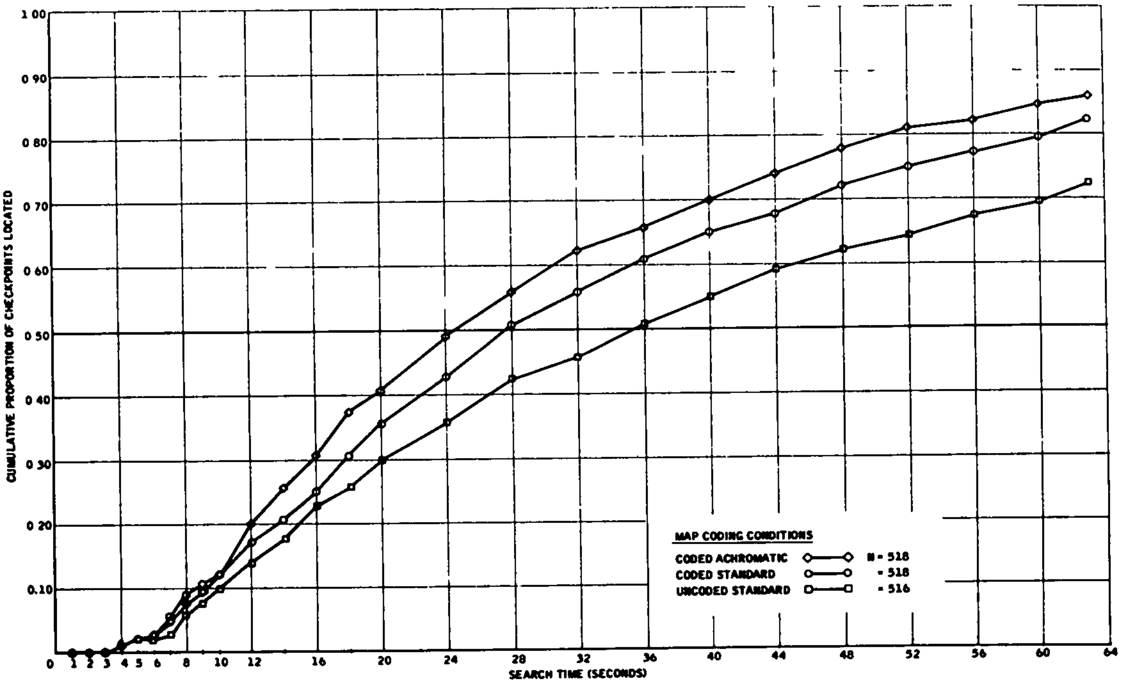

Fig. 24. Map coding by means of colored cues used on standard aeronautical charts and acromatized charts. (Ref. 8)

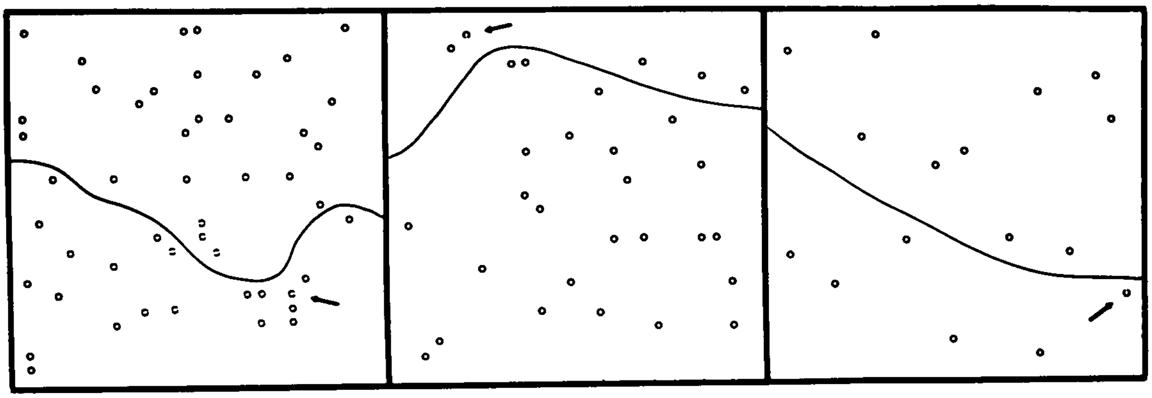

Fig. 25. Linear cues used by Erickson. Arrows point to the targets. (Ref. 5)

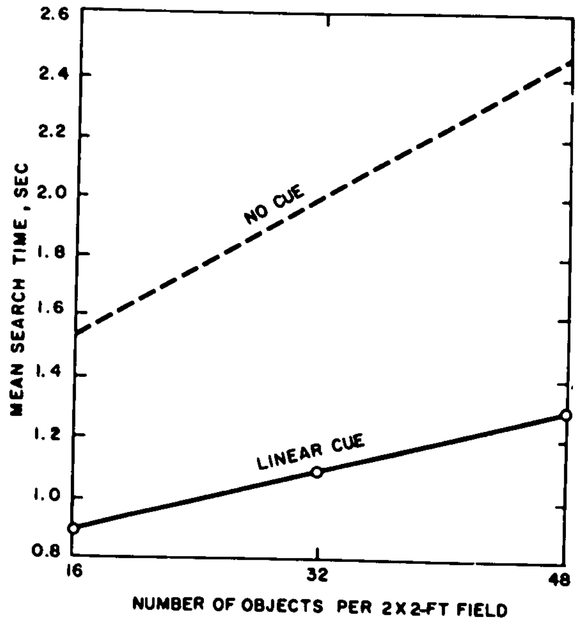

Fig. 26. Search time as a function of number of elements in the field for conditions in which a linear cue was absent or present. (Ref. 5).

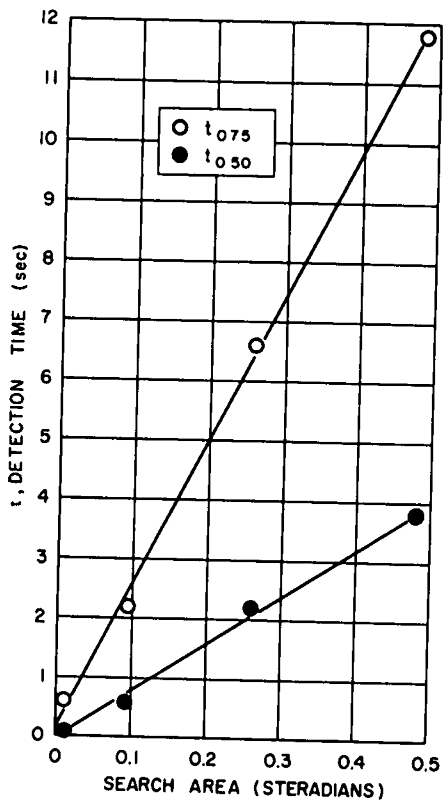

Fig. 27. Detection time as a function of the size of the area to be searched. (Ref. 6).

Environmental Factors

The search process is influenced inevitably by the environmental conditions in which it is undertaken. In a very general sense it can be appreciated that adverse weather conditions or any other circumstance which tends to degrade the imagery, whether directly at the eye or indirectly through photographic or other sensor-display chains, will likewise degrade search performance. Because of the sensitivity characteristics of the eye already noted, it has been found that the concept of the "detection lobe" is useful in the quantitative treatment of search problems. A brief example must suffice. The observer may be considered to carry with him a kind of imaginary, somewhat onion-shaped envelope in space, a figure of revolution derived from the central and peripheral contrast sensitivity gradients of his eyes. Objects at any given range and direction will fall either inside this lobe, in which case detection will be possible, or outside, where it will not be detected. The envelope itself is not hard-edged; that is to say, it may be drawn for any desired probability value. In the case of a downward-looking observer, the search probability and scanning procedures for best detection will be set by the intercept of this detection lobe and the ground plane. If the observer is in an aircraft at, say, 5000 ft. altitude, in most parts of the world the most obvious environmental factor will be the atmosphere. The effect of the absorption and scattering of light along the path of sight is always to reduce contrast, that is, to make the job more difficult. By the same token, it is as if the lobe size and shape were altered. In complicated cases, as for example, if pronounced haze layers are present, the distortion of the lobe may be severe. Because of the tremendous number of variables present, such problems are best handled by large computer programs such as the one now under development at the Visibility Laboratory.

Another class of environmental factors of importance are those which impose stress upon the observer. This problem has been worked on very little, if at all, and since search must frequently be performed under conditions of noise, vibration, fatigue and the like, it is clear that research in this area is needed.

Summary

Search is, as has been said, heavily dependent upon image evaluation. The quality of the images available is limited by the visual system of the observer, the properties of any intervening systems (photographic, electronic, or optical) and by the environmental conditions which prevail. A small start has been made in evaluating the importance of such stimulus-background factors as complexity, contrast, size, color, and duration. It cannot be said that we have approached a complete understanding of these factors and their interactions. A key question in the whole consideration of the search process concerns the manner in which the eyes are moved about the area being scanned. We will hear more about this from Dr. Gould. From a practical standpoint, we would like to know how to select and train people for the search task. We have not even considered the possibility of using regimented rather than free search, nor the use of mechanical aids for search purposes. A study by Townsend and Fry (14) showed, for example, that automatic scanning devices are feasible, but that they improved performance only for the difficult case of low contrast. At high contrast levels, free search was more successful.

I hope that by bringing out some of these underlying factors in the search process we may stimulate discussion of still others during the course of this symposium.

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