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Visual Search in Complex Fields: Size Differences Between Target Disc and Surrounding Discs

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An adaptable technique for performing search experiments, enabling extensive studies to be undertaken with well-practiced observers, is described. In each trial a single target disc was presented. Cumulative distributions of the times taken to locate 6 solid disc targets of varying size in a display containing 99 larger standard discs arranged in a regular fashion, and 3 disc targets in a display of 107 larger discs arranged irregularly, are presented. Three practiced observers were used with each display. Sixty readings per observer, per target, per display were obtained. It is suggested that for the targets most different in size from the background discs, the distributions of times to locate are largely dependent on response time factors; and for the targets closest in size the distributions are largely dependent on search factors. Some support is lent to theoretical work that suggests search times are exponentially distributed. The shortest time required to locate a particular target is used as an estimate of response time. Response times are found to be inversely proportional to both the difference between the log of the target and nontarget disc diameters, and to the difference between the diameters. An amendment, taking response time into account, is suggested for exponential search equations.

INTRODUCTION

Gottsdanker (1960) has isolated several search determinants. One of these, the competition determinant, refers to the search situation in which the target is clearly distinguishable from its immediate background, but is difficult to detect because it is confusable with other, nontarget stimuli that are also present in the search area. The difficulty is one of discrimination. Obviously, the smaller the differences between the target and the other stimuli, the harder the search task. The target may differ from the nontargets along the dimensions of color, contrast, shape, and size. Other variables to be considered are the number, density, and distribution of the nontarget stimuli and the size of the search area.

There are several studies of the competition search situation. Increasing nontarget density (and number, with search area constant) produces increases in search time, when the target differs in shape from the other stimuli (Eriksen, 1955; Erickson, 1964; S. W. Smith, 1962) and when it is a particular number in an array of digit combinations (Green and Anderson, 1956; McGill, 1960; S. L. Smith, 1962). Increasing number (and search area, with density constant) has a similar effect, whether the target is different in shape (Brody, Corbin, and Volkmann, 1960; Johnston, 1965) or is a particular number in other digits or a letter pair in other letter pairs (Cizkova, 1967). When stimuli of varying color, shape, size, and contrast are used as nontarget stimuli, search time increases as the heterogeneity of the other stimuli increases (Eriksen, 1953).

S. W. Smith (1962) not only investigated density but systematically varied differences between target and nontarget stimuli. Using circles as background stimuli, he found that, as the target varied in shape from triangle through square and pentagon to hexagon, search time increased over a large range of nontarget densities. In addition, he found that search time decreased, as an increasing contrast difference was added to a shape difference (square target in a background of circles), and that it decreased more, if size differences were also added. Smith did not present search time distributions: his data points were the average of his observers' median search times.

The aim of the present work was to investigate the effects of size differences alone. A task was needed that allowed observers to undertake many search trials. Repeated testing is not possible if only a small set of the apparently possible target positions are used, since the observers could quickly learn the limited set of actually possible positions. Studies using a small number of stimulus cards (Eriksen, 1955; Green and Anderson, 1956; McGill, 1960) have, therefore, had to use comparatively untrained observers, pooling their data, thus obtaining an indication of the effect of the variables involved but, possibly, obscuring the underlying processes of search behavior. The present search task was designed so that all apparently possible target positions were actually possible, and so that the target could be moved quickly from one position to another from trial to trial.

METHOD

The search displays were perspex sheets with shallow holes drilled in predetermined positions in their surfaces. Ball bearings of varying sizes were placed in the indentations, and the displays were masked off to give search areas of the required shape and size. The displays were placed on an overhead projector and projected onto a screen.

With this arrangement, target position was changed rapidly, with tweezers, from presentation to presentation, in accordance with a previously determined random order. The number of positions that the target could occupy was limited only by the total number of stimulus positions in a particular display.

The observer was seated in front of the display and behind a shutter. He opened the shutter when he began to search and closed it again as soon as he found the target. The length of time the shutter was open was recorded automatically. The observer indicated verbally where he thought the target was, after the shutter had been closed. The arrangement for projection is shown in Figure 1.

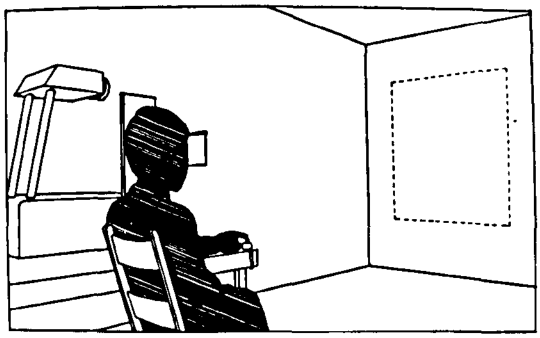

Figure 1. Sketch of experimental arrangement showing overhead projector shutter, response button, screen, and the position of the observer.

Data are reported for two displays. With the observer 9 ft. from the screen, the displays were square, with sides of 16°20′ in length: the actual length was 4.5 in. unprojected and approximately 2 ft. 7.5 in. projected. One display had 100 indentations arranged regularly in a 10 × 10 matrix. For the second, one-third of the 324 intersections of an 18 × 18 grid were selected at random to give a 108-position irregular display. The displays are shown in Figure 2.

The diameters of the seven discs used as targets and background stimuli are shown in Table 1. For each search trial, one target was presented among the nontarget background stimuli. The target was of size A, B, C, D, E, or F for the regular display, and of size A, B, or C

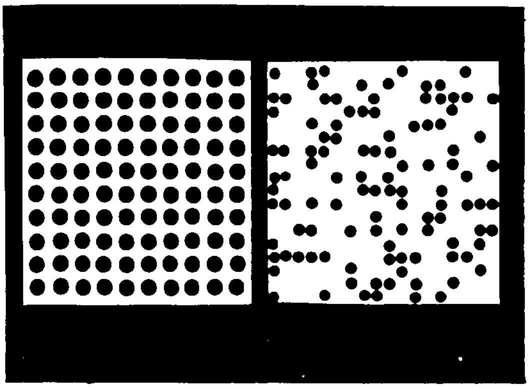

Figure 2. Regular and irregular search displays, each containing a target disc slightly smaller than the background stimuli.

for the irregular. The background stimuli were of constant size: G for the regular display, D for the irregular. Target positions were randomized so that for each search trial the target was equally likely to appear in each possible position on the display.

After a run of ten consecutive searches for a given size of target, the observer had a short rest. Each experimental session consisted of six such runs. The sessions lasted just under one hour. The order of presentation of the six runs was randomized for each session.

Three observers (S1, S2, and S3) with normal vision (one corrected) were used. They took part in at least three full sessions, as practice, before the data reported here were collected. These were followed by six experimental sessions for the regular display and three for the irregular, giving 60 readings per target per display per observer.

RESULTS

Search data is often reported in terms of mean or median times. Figure 3 shows the frequency distributions of search times for one observer searching the regular search display. The times increase in variability and become highly positively skewed as the difference in size of the target and nontarget discs decreases. Thus mean times become less and less appropriate as measures of central tendency. Median times are perhaps better. However, a full description of search behavior should take account of the fact that, as the discrimination of a target from nontargets becomes more difficult, mean and median times, variability and range increase, and the search time distributions become more and more highly positively skewed. The most appropriate way of presenting this information is in terms of cumulative distributions, the way in which Krendel and Wodinsky (1960) gave their data for search for targets of varying size and contrast in plain backgrounds: i.e., giving the number of occasions on which each target is found within each given duration.

Figure 4 shows the cumulative distributions of times for three practiced observers searching the regular display (Figure 4a replots the data shown in Figure 3). Figure 5 shows the data for the irregular display. As the target/nontarget difference is reduced, search times increase. The increase is more marked as the proportion of targets detected increases.

TABLE 1
Diameter of Discs Used as Target and Background Stimuli

	Discs						
Measure	*A*	*B*	*C*	*D*	*E*	*F*	*G*
Unprojected (32nds of in.)	4	5	6	7	8	9	10
Projected (in.)	$\frac{7}{8}$	$1\frac{3}{32}$	$1\frac{5}{16}$	$1\frac{17}{32}$	$1\frac{3}{4}$	$1\frac{31}{32}$	$2\frac{3}{16}$
Angular (min. of arc)	27.2	34.0	40.8	47.6	54.4	61.2	68.0

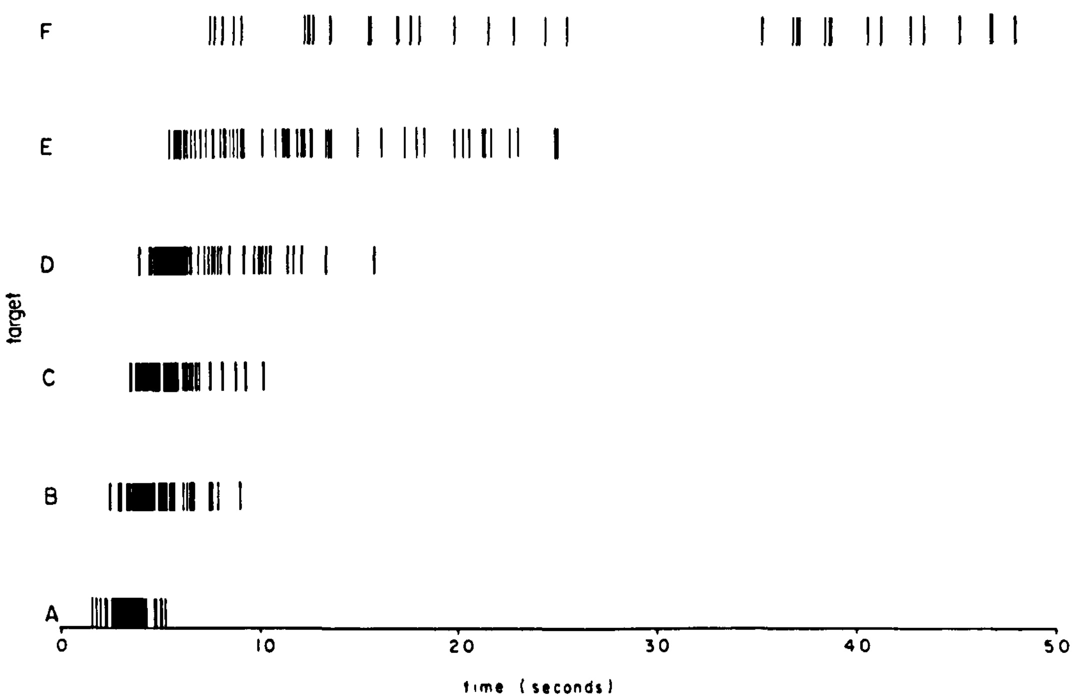

Figure 3. Frequency distributions for targets A-F (distribution for F continues up to 43.70 sec.) in the regular display: Observer S1.

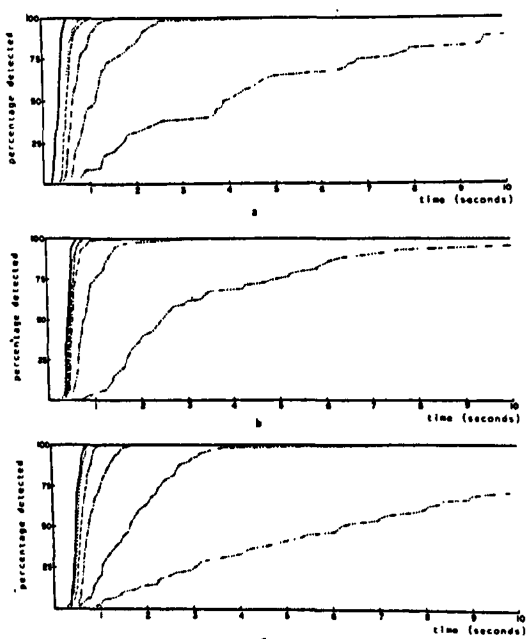

Figure 4. Cumulative distributions for targets A-F in the regular display of background stimuli G: 60 readings per distribution. (a) S1, (b) S2, (c) S3. ———A, ...B, ... C, .-.-.-.D, ..-..-..-..E, ...-...-...F.

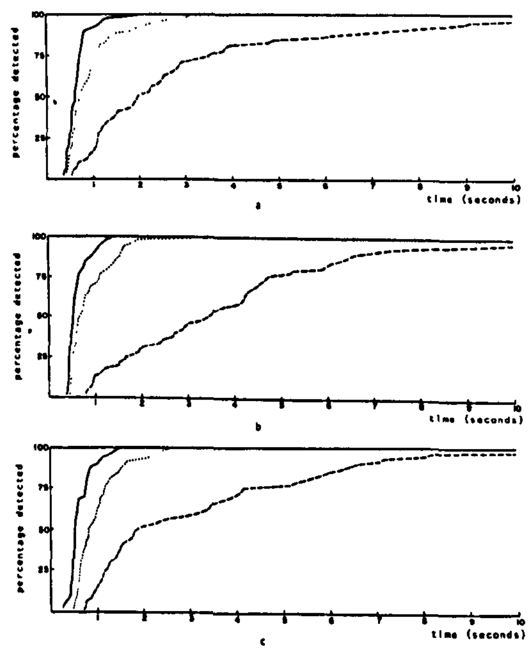

Figure 5. Cumulative distributions for targets A-C in the irregular display of background stimuli D: 60 readings per distribution. (a) S1, (b) S2, (c) S3. ———A, ... B, ... C.

DISCUSSION

Search and Response Time Factors

Search is only necessary when, for some reason, a target cannot be located immediately. If a target is perceptually prominent, very little search will be necessary and varying its position in the display will have little effect. There will be little spread in the times needed to locate such a target and the resultant cumulative distribution of these times will be comparatively steep.

The point on the target-background difference-continuum at which search becomes necessary is within the range of values used with the regular display (Figure 4). The distributions for the targets most different in size from the background stimuli (A, B, and C for S1 and S2; A and B for S3) are very steep, suggesting that little or no search was necessary to locate them. The times obtained are perhaps best considered as response times which have two components, a reaction time dependent on how efficiently the observer can manipulate the shutter, and a processing time in which he decides whether or not he can see the target.

The distributions for the remaining targets appear to be increasingly dependent on search factors, as well as containing elements of response time factors. For middle range differences (with target D for S1; D and E for S2; C and D for S3) the distributions are fairly steep at first, but later have a more gradual incline. Probably, for these target-background differences, most of the display can be covered in one or two fixations, with a few target positions toward the boundary requiring more. This view is supported by the fact that, for all three observers the times to locate such targets (and the three most different targets) when they occur in the outer ring of stimuli of the display tend to be longer than those obtained when they are placed more centrally. For the targets closest in size to the background stimuli, the time distributions have more gradual slopes (targets E and F for S1 and S3, and F for S2). Many fixations will be needed for most presentations of these targets. With target F, for all observers, search times tend to be longer the farther toward the bottom of the display that the target occurs. Some form of horizontal scanning beginning at the top of the display seems to be indicated for this target.

With the irregular display (Figure 5), all three targets (A, B, and C) seem to be close enough in size to the nontargets (D) to have required search. Again, as the target-background similarity increases, the distributions become increasingly dependent on search factors.

Fitting Exponentials

Much of the extensive data of Krendel and Wodinsky (1960) could be fitted to exponential functions of the form

$$P_T = 1 - (1 - P_s)^{T/t_s} \qquad (1)$$

where:

P_T is the probability of locating a target by time T;

P_s is the probability of detecting a target in a single fixation; and

t_s is the average time for a fixation.

(This notation is not exactly the same as Krendel and Wodinsky's: they also included the time between fixations in the term that t_s replaces, but this is omitted here, since it is small relative to t_s.)

Several theoretical approaches to search (Davies, 1968; Howarth and Bloomfield, 1968, 1969; Krendel and Wodinsky, 1960; McGill, 1960; Williams, 1966) have incorporated the idea that search times should be exponentially distributed. Figure 6 shows, replotted on semilog scales, the distributions for those targets (D, E, and F for S1 and S2; C, D, E, and F for S3) that required some search in the regular display (from Figure 4). Figure 7 replots,

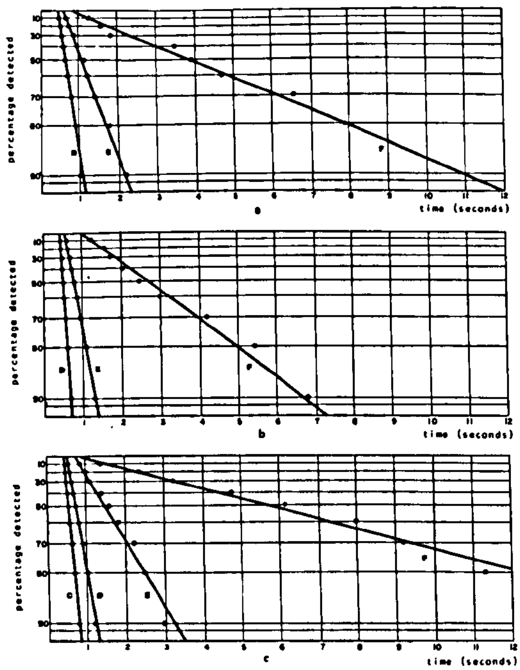

Figure 6. Search-dependent cumulative distributions from Figure 3 replotted on semilog coordinates. (a) S1, (b) S2, (c) S3.

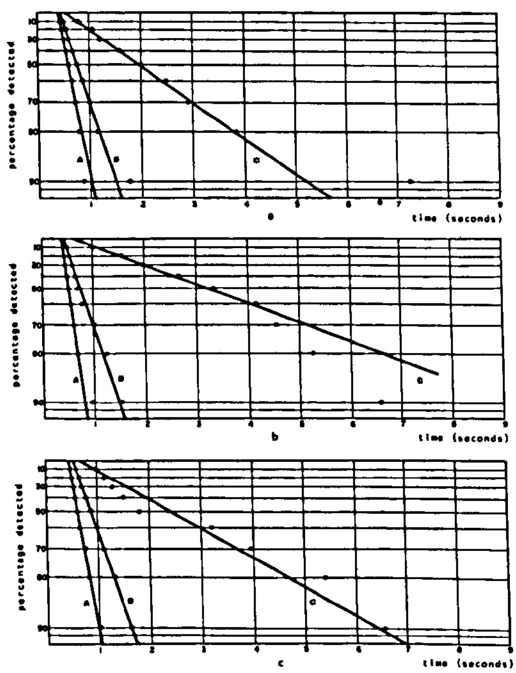

Figure 7. Cumulative distributions from Figure 4 replotted on semilog coordinates. (a) S1, (b) S2, (c) S3.

similarly, the distributions of the three targets used with the irregular display (from Figure 5). Straight lines, fitted by eye, have been included on both figures. The data are seen to fit least well for the targets most similar to the non-targets: i.e., for those which are more dependent on search factors.

Response Time Functions

The cumulative distributions neither pass through the origin of the graphs nor have a common origin, as the exponential theoretical treatments suggest they should. In fact, the origins of the distributions can be considered as the response times required by the observers to respond to the presence of a target with no element of search; i.e., when the proposed search begins with the observer looking directly at the target. We may take t_f, the fastest time obtained, as an estimate of response time, t_r: t_r will be equal to or less than t_f. The extent of the approximation involved here depends upon the number of presentations of each target. The larger the number, the more likely it is that a target would be positioned so that no search is necessary. With 60 presentations of each target, per display, per observer, and displays of 100 and 108 elements, the approximation probably results in only a small error.

Inspection of Figures 4, 5, 6, and 7 shows that t_f increases as the degree of similarity between target and nontargets increases. Two functions, at least, can adequately describe this relationship.

Crossman (1955) suggested that the time needed to distinguish one stimulus from another, t_{dis}, was proportional to a confusion function, C, defined, in terms of the physical size of the two stimuli, x_1 and x_2, as follows:

$$C = \frac{1}{|\log x_1 - \log x_2|} \qquad (2)$$

If x_1 and x_2 are equated with nontarget and target areas, equation (2) becomes

$$C = \frac{1}{\left|\log\pi\left(\frac{d_B}{2}\right)^2 - \log\pi\left(\frac{d_T}{2}\right)^2\right|} \quad (3)$$

which reduces to

$$C = \frac{1}{2\,|\log d_B - \log d_T|} \quad (4)$$

where:

d_B and d_T are the diameters of the background and target stimuli, respectively.

Assuming that t_f can be equated with t_{dis}, plotting t_f against $1/(\log d_B - \log d_T)$ should result in a straight line. Figure 8 shows such a plot, with t_f averaged over the three observers, for the regular and irregular displays, with the addition of the lines of best fit, obtained by the method of least squares.

Howarth and Bloomfield (1968, 1969) suggest that, in competition search tasks, mean search time is related to a function D of background and target diameters, thus:

$$D = \frac{1}{(d_B - d_t)^2} \quad (5)$$

It was found that t_f could also be related to $\sqrt{D}$, as shown in Figure 9. Again, the method of least squares was used to obtain the lines of best fit.

In Figures 8 and 9 the intercepts on the t_f axis represent response times for very easy targets in the particular backgrounds. A large proportion

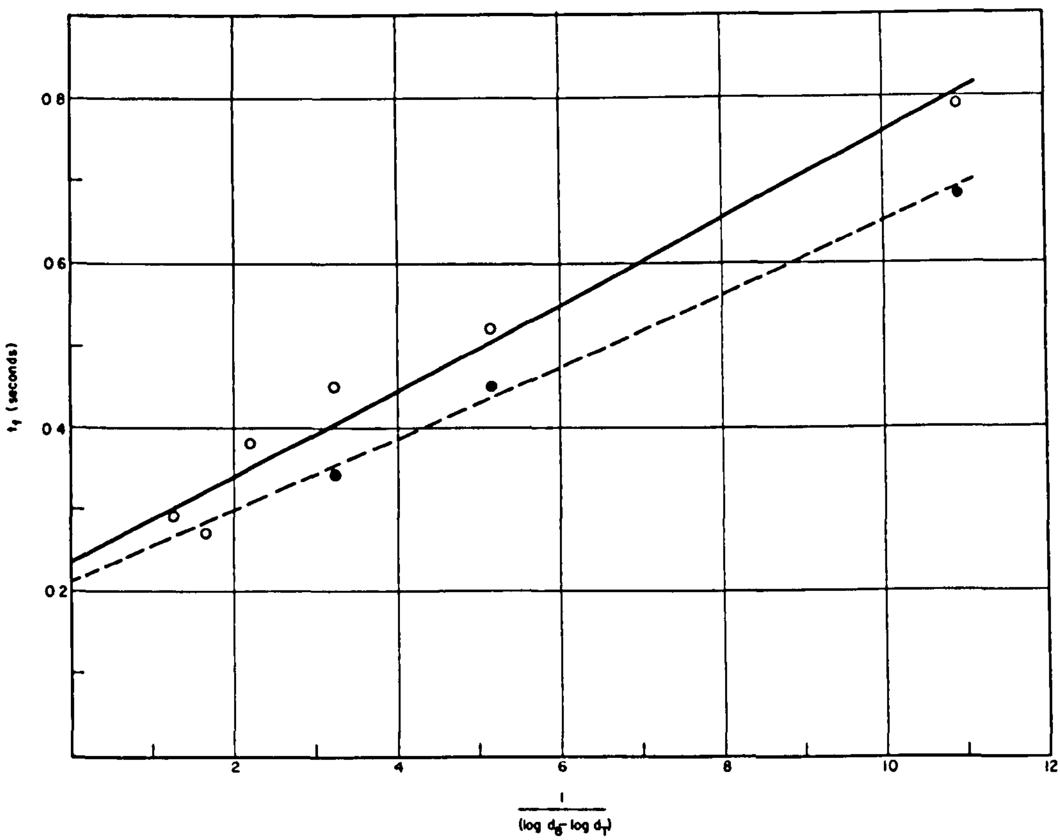

Figure 8. Relation between t_f, fastest search time, and $1/(\log d_B - \log d_T)$, (d_B and d_T are diameters of background and target disc). t_f averaged over three observers. o———o Regular display, line of best fit: $t_f = 0.239 + (0.0259)/(\log d_B - \log d_T)$. •– – – – –• Irregular display, line of best fit: $t_f = 0.212 + (0.0216)/(\log d_B - \log d_T)$

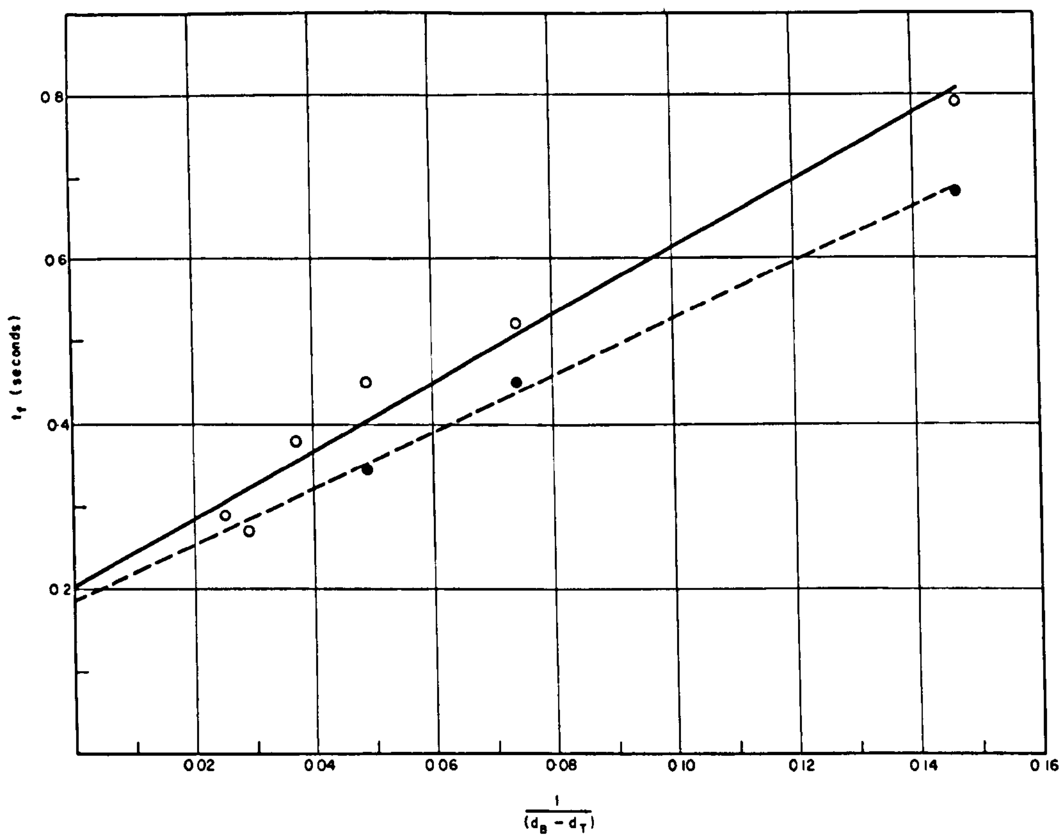

Figure 9. Relation between t_f and $1(/d_B - d_T)$. t_f averaged over three observers. o———o *Regular display, line of best fit:* $t_f = 0.204 + (4.09)/(d_B - d_T)$. •······• *Irregular display, line of best fit:* $t_f = 0.184 + (3.41)/(d_B - d_T)$.

of this time will be simple reaction time with, perhaps, a comparatively small element of processing time. The difference between the intercept and values of t_f for other, more difficult to discriminate, targets will be the additional processing time necessary to distinguish these targets from nontargets.

The predicted values of t_f from the regression equations derived in both ways are virtually identical. In addition, the variance of t_f can be accounted for by the equations almost equally well. For the regular display, 96.58% of the variance is accounted for by the relation derived from the confusion function, and 96.66% by the simpler diameter difference relation. For the irregular, the percentages are 99.27% by the former and 99.36% by the latter.

It seems justifiable to suggest a general equation relating response time and a diameter function, F(dia), thus:

$$t_r \doteq t_f = a + b{:}F(\text{dia}) \qquad (6)$$

where:

a is the intercept on the t_f axis;

b is the gradient of the line; and

$F(dia)$ is given either by:

$$F(dia) = \frac{1}{|\log d_B - \log d_T|}$$

$$\text{or } F(dia) = \frac{1}{|d_B = d_T|} \qquad (7)$$

Amending the Basic Exponential Search Equation

Response time is not included in the exponential function of equation (1) and the equation would be more realistic if amended as follows:

$$P_T = 1 - (1 - P_s)^{(T - t_r)/t_s} \quad (8)$$

with t_r defined by equations (6) and (7). In the study reported here, P_T and T have been measured and t_r has been estimated. To make a detailed comparison of these data and predictions from equation (8), measures of P_s and t_s are also needed. These were not obtained for S1 and S2, or for S3 with the irregular display. For S3 with the regular display, P_s was estimated for a fixed exposure time of 0.25 secs. Equating this exposure time with t_s and using the estimated values of P_s, equation (8) does not predict the obtained cumulative curves at all well. However, t_s varies with target difficulty (Bloomfield, 1970, pages 140–141 and 161) and the values of t and P_s used in this comparison may be inappropriate. Evaluation of equation (8) must wait until accurate measures are obtained for all the variables it relates together.

For the moment, the empirical data presented here for observers searching in regular and irregular competition search displays suggest this simple amendment to basic exponential search theories. In addition, the data should provide a base line against which it will be necessary to test future developments of search theory.

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