Visual search through random walk number fields¹

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Serial search through ordered number fields (resembling two-dimensional random walk patterns) was studied. A method employing generating discs allowed for constructing the number fields in such a way as to vary systematically the serial constraint (step size and variability of step size) between consecutive numbers in the field. In Experiment 1, performances on constrained number fields were compared with those on a randomly generated number field. The number of points serially connected in 30-sec trials increased with increasing constraint in the construction of the number field. In Experiment 2, step size and variability of step size were combined orthogonally in the construction of the number fields. Both variables had significant effects on number of points connected. In addition, learning effects were shown to occur over the 10 trials of practice. Two explanations of serial search behavior are mentioned, one based on local density in the number field and the other on area searched through in seeking a target.

An important distinction can be made between discrete and serial search through number fields (Underwood, 1966). With discrete search, the S's task is to find a single number from among the many in the field (Green & Anderson, 1956; Williams, 1966). In serial search, the S's task is to detect, in order, a series of targets. For example, in one type of task the S searches serially for consecutive numbers that are arrayed randomly on a page of paper. As the S searches, he connects points by drawing lines between consecutive numbers. This task has been used to study effects of massed vs distributed practice on search behavior (Underwood, 1961). Another variant of serial search in which numbers are *not* randomly arrayed is the task employed in children's draw-by-number books. In this case, there are constraints on the placement of the consecutive numbers so that drawings of animals, attractive nymphs, etc., are produced when the numbers are connected consecutively.

The foregoing examples suggest that it would be of interest to systematically vary the constraint on the placement of the numbers, ranging from high-constraint

conditions to random placement. In the present study, a method of numerically varying the constraint is introduced. It employs circular generating discs to produce two-dimensional arrays of numbers that, when connected successively, resemble a random-walk pattern. By varying parameters of the generating discs, it is possible to construct random-walk number fields with fixed or variable step sizes between consecutive numbers. Step size between serially related items is known to be an important variable in memory search (Weber, Cross, & Carlton, 1968; Weber & Castleman, 1969) and may be in visual search.

EXPERIMENT 1

Procedure

Each S had 10 number-field pages, alternated with blank rest pages. At the center of the number-field pages was a circled number, 10. Other two-digit numbers, from 11 to 78, were scattered about the page, according to one of four different schemes to be described shortly. The S was to place his pencil on the number 10 and to connect and circle as many successive numbers (10, 11, 12, . . . , 78) as possible in a 30-sec period. On the order "Stop" from the E, the S turned to the next page (a blank masking sheet) and rested for 30 sec. At the end of this interval, the E said, "Start," and the S turned to a new page with the same number field, started with the number 10, and again connected as many number points as possible. This procedure was followed for 10 trials. The basic datum was the number of points (two-digit numbers) connected in each 30-sec trial.

Materials

The number fields were generated on 8½ x 11 in. pages by using a modified random-walk procedure. Each digit was about 2/16 in. high, appeared in black on the white paper, and was readily visible. For Group 1F, a fixed distance of 1.0 in. between consecutive numbers was used. The number field for this group was generated by employing an acetate disc of 1-in. radius that had its perimeter divided into six arcs of 60 deg each. The first point, number 10, was placed in the center of the page. Then the generating disc was placed with its center on 10. A random selection from the six arcs on the perimeter of the generating disc was made, and the number 11 written on the arc, a distance of 1.0 in. away from the number 10. Next, the center of the disc was moved to the number 11, another arc on the disc perimeter randomly chosen, and the

number 12 written there; and so forth for the remaining numbers, up to 78.

In Group 2F, the generating disc had a fixed radius of 2.0 in. and in other respects the number field for it was generated as in Group 1F.

In Group 1.5V, the average distance between points was 1.5 in. This was obtained by using the 1.0- and 2.0-in. discs of the previous conditions and alternating randomly between them, with the restriction that each disc be used twice in a set of four points. So, in this case, the step size varied over two values.

In a fourth condition, Group R, the number pairs 11 to 78 were located randomly by employing a two-dimensional coordinate system, 10 lines to the inch. The location of each point was then given by assigning an X, Y coordinate from a random-number table.

For all conditions, the resulting number fields were reasonably well dispersed on the 8½ x 11 in. pages, although there were local variations in density that differed from one condition to another. Also, it should be noted that for Conditions 1F, 2F, and 1.5V, there were some minor departures from the foregoing procedure. If a number point fell near the edge of a page, it was possible for the next point to go off the page; in that case, only those arcs of the generating disc that would keep the next point on the page were sampled. Such departures were not frequent, occurring for fewer than 8% of the cases. Also, when a given 60-deg arc of the disc was selected randomly, it was still necessary to select the part of the 60-deg arc on which the number point was to appear. This selection was made in such a way as to keep the new point separated from any prior points, in other words, to avoid clutter and overlap.

Subjects

The Ss were undergraduate volunteers from Kenyon College. They were run in several separate group administrations. The four conditions were assigned randomly to seats, so that within a given administration approximately the same number of Ss was run for each condition. There were 40 Ss, 10 per group.

Instructions

Instructions were kept to a minimum and served only to let S know about the procedure of alternating between trials and rest periods, how to circle and connect consecutive numbers, and that the problem was to learn to connect as many numbers as possible across trials.

Results and Discussion

Table 1 gives a summary of results in terms of points connected per 30-sec trial; the remainder of the table will be discussed shortly. It is seen that the nature of the

Table 1
Search Rates and Distances Covered

Group ^a	Points Connected/30 Sec		Mean Distance (in.) Traveled/30 Sec
	M	SD	
1F	33.68	9.29	33.68
2F	23.03	7.46	46.06
1.5V	20.81	6.71	31.21
R	9.01	3.15	46.81

^a N = 10 per group

step in the random walk has a large effect on search rates. Group 1F connected the largest number of points, followed by Groups 2F and 1.5V, with the random-condition Group R showing the least number of points connected. An analysis of variance indicates significant effects [$F(3,36) = 46.63$, $p < .001$]. A Newman-Keuls multiple-comparisons test shows that every mean differs significantly ($p < .05$) from every other mean, with the exception of the pair from Groups 1.5V and 2F ($p > .05$). Learning effects were also observed for each condition over the 10 trials. The effects were similar to those to be presented in the next experiment.

Although size of the random-walk step was an important variable, it could have acted in at least two distinct and not equally interesting ways. (1) The observed differences could have been due to a perceptual searching through of the number field; with longer "steps" between numbers, a larger segment of the field was, on the average, searched through before the target was found. (2) The observed differences could just as well have been due to writing speed. With larger step sizes, the lines connecting consecutive numbers also

increased in length, possibly requiring more writing time.

These two alternatives may be distinguished, at least partially, by examination of Table 1. For Groups 1F and 1.5V, the average distance in inches covered per trial is about the same; yet, in terms of number of points connected, these two groups differed significantly. The same holds for Groups 2F and R. In another comparison, Groups 2F and 1.5V connected about the same number of points per trial, but the distance traversed in the two conditions is considerably different. The evidence indicates that at least a large portion of the experimental effects are attributable to visual search processes as opposed to writing speed.

EXPERIMENT 2

Because Experiment 1 failed to use a factorial design, it was not possible to arrive at a separation of effects due to step size vs variability of step size. The second experiment was designed to separate these two factors and to clarify several other points. Two average step distances of 1 and 2 in. were combined orthogonally with a fixed or a varied size of step to yield four groups.

Method

Groups 1F and 2F used the same number fields generated for Experiment 1 with the 1.0- and 2.0-in. discs, respectively. For Group 1V, two different generating discs, with radii equal to 0.5 and 1.5 in., were alternated randomly in the construction of the field. Hence, the average step size was 1.0 in. but varied between the two indicated values. Group 2V had its number field generated

Table 2
Search Rates and Field Density

Group ^a	Points Connected/30 Sec		Mean Local Density
	Mean	SD	
1F	31.55	8.41	5.23
2F	21.84	6.22	2.74
1V	24.04	7.71	5.52
2V	12.18	4.33	4.12

^a N = 16 per group

by randomly alternating between generating discs with radii of 1.5 and 2.5 in. This produced an average step size of 2.0 in., also varying between two values.

The resulting four number fields were widely dispersed across the pages. Their overall densities were, of course, equal, with 69 numbers per page. However, they clearly differed in visual appearance, as reflected by variations in local density. Since density is known to be an important variable in discrete search (Eriksen, 1955), it was proper to assess it in the disc generation procedure used here. Accordingly, a unit disc with a radius of 1.0 in. was used to measure local density. Starting with the number 10, the E moved the unit disc consecutively through all the points in the number field. The values in the last column of Table 2 indicate the mean number of points located within the perimeter of this unit disc as it was moved through its successive locations. The larger values correspond well to number fields that seem visually to be more dense in local areas.

The Ss were from psychology classes at Oklahoma State University, and they were required to serve. There was a total of 64 Ss with 16 per group. The experiment was group administered, and instructions and other details were the same as in Experiment 1.

Results

A summary of results in terms of points connected per trial is shown in Table 2. Points were connected more rapidly for a step size of 1.0 in. than for a step size of 2.0 in. and also more rapidly for fixed than for varied step distances. Both effects are statistically reliable. For 1.0- vs 2.0-in. steps, $F(1,60) = 153.51$, $p < .001$; and for fixed vs varied steps, $F(1,60) = 98.55$, $p < .001$. The interaction is not significant ($p > .05$). A Newman-Keuls test shows that all pairs of means differ significantly ($p < .05$) except for Groups 1V and 2F ($p > .05$).

Learning effects are shown in Fig. 1, where mean number of points connected is shown as a function of trials. To serve as a point of reference, Group R, the random

Fig. 1. Search rates as a function of trials and condition.

condition from Experiment 1, is also shown. It is not strictly comparable because the Ss in the two experiments are from different institutions, but it is probably a good first approximation. It should be noted that only Trial 1 gives a pure measure of visual search. Subsequent trials are mixtures of search behavior and learning, although the same rank ordering of performance is evident for every trial.

DISCUSSION

It is reasonable to inquire if one single explanation can account for both main effects, step size and variability of step size. Two possibilities are suggested. They deal with (1) local field density and (2) area of the generating discs used to produce the number fields. The local density values in Table 2 bear a low positive correlation to the mean number of points connected (Table 2). The usual density explanation (Eriksen, 1955) indicates that the larger the density, the slower the search and would require a negative correlation. Hence, in a serial search task of this type, field density, within the present limits, does not give indication of being an important variable. A qualification is in order, however. The use of a unit disc to measure density is purely arbitrary. Some other radius or perhaps some other geometric form might yield a different set of relations for local density and search performance.

An alternative explanation is forthcoming if the area of the largest generating disc is considered for each of the variable conditions. In Condition 1V,

the largest disc has a radius of 1.5 in. as opposed to 1.0 in. in Condition 1F. The respective largest areas are 7.06 and 3.14 in.². A similar comparison of Conditions 2V and 2F shows respective largest areas of 19.62 and 12.56 in.². Thus, even with average step size held constant, larger areas must be scanned for variable than for fixed conditions. This suggests that for the conditions studied, the number of points connected is functionally related to the area searched through rather than the density within that area.

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Selection strategies and reversal-nonreversal shifts in verbal discrimination transfer

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Verbal discrimination transfer with structured lists that permit the operation of an intrapair selection strategy was compared for reversal and nonreversal shift conditions. Reversal transfer was significantly superior to nonreversal

transfer. However, reversal transfer did not differ significantly from a control condition in which the selection strategy was operative on the transfer list only.

Kausler & Farzanegan (1969) recently provided evidence for the operation of a selection strategy during verbal discrimination (VD) learning and transfer when the intrapair wrong (W) and right (R) items differ systematically on a

preexperimental dimension, such as word frequency. In their transfer test, Kausler and Farzanegan employed conditions analogous to the reversal and partial reversal shift conditions indigenous to other verbal learning tasks (e.g., Kendler, Kendler, & Sanders, 1967). Their use of a single dimension (word frequency) in constructing lists, however, precluded the inclusion of a nonreversal shift condition. By employing W and R items that varied systematically on two dimensions (word frequency and word length), the present study permitted a contrast between reversal and nonreversal shift strategies in VD transfer. Generalizing from other areas of research on reversal-nonreversal shifts (Kendler & Kendler, 1962), it was hypothesized that a reversal shift strategy would be more efficacious than a nonreversal shift strategy in VD transfer.

METHOD

The 96 Ss, undergraduate students who were naive with respect to prior participation in discrimination-learning studies, were assigned alternately to the three groups (N = 32), two experimental and one control, representing the three main conditions of the study. The Ss in each group learned two 12-pair lists conforming to a W₁-R₁, W₂-R₂ VD transfer paradigm (Kausler, Fulkerson, & Eschenbrenner, 1967). That is, different sets of specific words served as W and R items on the two lists. However, the words on both lists were selected on the basis of two dimensions, frequency and length, each with two attributes (low and high frequency; four letters and seven letters). List 1, for both experimental conditions (Groups RV and NRV), permitted a selection strategy in which one of the dimensions was the relevant one differentiating between Intrapair W and R items and the other dimension was irrelevant with respect to intrapair discriminations. List 2 for the reversal condition (Group RV) continued to have the same relevant dimension, but with the attributes associated with W and R items on List 1 now being reversed. For the nonreversal condition (Group NRV), the irrelevant dimension of List 1 became the relevant dimension of List 2, and the relevant dimension of List 1 became irrelevant. For the control condition (Group C), List 1 did not permit the operation of a systematic selection strategy based on the word dimensions. List 2, however, contained relevant and irrelevant dimensions in common with the two experimental conditions. Between-group variations were derived by way of List 1. That is, all three groups received a common List 2.