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# ATTENTION IN THE IDENTIFICATION OF STIMULI IN COMPLEX VISUAL DISPLAYS [1]

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The identification of 3 stimuli embedded in brief foveal displays was studied under conditions varying the relationship between the relevant stimuli; the stimulus displays and responses were the same in all conditions. Performance was best when the stimuli were the 3 dimensions of a single object, and better when they were the same dimension than when a different dimension of each of 3 objects. In the multiple-object conditions, accuracy was correlated with serial order of the responses. However, the 3 responses to each display were independently accurate within all conditions. It was suggested that the "span of attention" is not fixed. In a supplementary experiment, the spatial separation of the relevant stimuli was found to have no effect.

Behavior occurs in response to physical stimulation. However, only a limited portion of the physical energy impinging on an animal is effective in determining its behavior, and a stimulus which at one time evokes a response may at another time fail to do so. The "stimulus" is a reduction of the input to the sensory receptors. The concept of *attention* concerns this reduction.

One question suggested by the concept of attention is the following. If an *O* responds to (i.e., "attends to") some specific and denotable stimulus, then what additional concurrent stimuli have been perceived and might also be responded to? This is closely related to the "span of attention" or information "channel capacity" problem. The question is, as the structuralists asked: What are the basic elements of stimulation?

One approach to this question has been the study of the effects of "set" in perception (e.g., Bruner, 1957). However, when *S*'s "set" is manipulated by directly varying the number of response alternatives for identifying a *single* stimulus, several experiments have failed to support the perceptual set hypothesis (e.g., Hodge & Pollack, 1962; Lawrence & Coles, 1954; Long, Reid, & Henneman, 1960).

It would seem evident, though, that the opportunity for attentional selection is greatest in conditions providing a large amount of stimulus information for brief durations. In fact, the view is widespread that the human *O* operates as a channel with fixed, and thus limiting, capacity (e.g., Eriksen & Lappin, 1967a; Garner, 1962; Miller, 1956). As might be expected, results indicative of selective attention appear in several experiments in which *S* is explicitly asked to respond to multiple stimuli or multiple stimulus attributes (see Broadbent, 1958; Eriksen & Lappin, 1967b; Garner, 1962, Chapter 4; Montague, 1965; Rudov, 1966; Shepard, 1964).

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The general task in the present study requires the identification of stimuli embedded within multidimensional multiobject displays. Designation of the relevant stimuli is simultaneous with the display, which is presented for durations too brief to permit voluntary eye movements. While the total information in each display is presumably well beyond *S*'s channel capacity, the relevant stimulus information is by previous indications well within such limits. In all conditions the stimulus set and the response categories remain the same; the experimental variables deal only with the *similarity* (spatial and dimensional) of the stimuli to be identified on a given trial.

Two dependent variables are of interest: identification accuracy, and the correlation in accuracy of responses made on the same trial.

## Experiment I

### *Method*

*Stimuli.*—Stimuli were presented in a Scientific Prototype Model GB three-field tachistoscope. Prior to the stimulus exposure, which was triggered by *S*, *S* fixated a small black cross against a background of 5 ftl. Stimulus displays were presented in one field and indicator pointers (as explained below) were simultaneously presented in the third field. Luminance of the stimulus display was 5 ftl., and luminance of the small pointer was 11 ftl.

The stimulus displays were composed of nine circles differing in size, angle of a line through center, and color. There were three alternatives for each of the three variables, which were orthogonally combined. Thus, each of the nine objects in the display was one of 27 possible. These particular stimulus variables were chosen with the intention of bearing relevance to previous research. Color would seem likely to operate independently of the circle size and line orientation (Eriksen & Hake, 1955). Question has been raised, however, as to the independence of the latter two variables (Lockhead, 1966; Shepard, 1964).

The nine objects were centered at equally spaced points around an imaginary circle 1° of visual angle in radius from the fixation point. The stimuli were stenciled on white vinyl cards with colored pencils. The three colors (designated "red," "purple," and "blue") were selected to fall at approximately equal intervals on a hue continuum. The three sizes of the circles ("small," "medium," and "large") were 21, 25, and 29 min. of visual angle in diameter. Correlated with this diameter was the length of the line passing through and slightly outside the circle. These lines (designated "down," "middle," and "up") were inclined 20°, 45°, and 70° from the horizontal.

A set of 27 displays of nine such objects was constructed. The values of each dimension were randomly assigned to the nine positions in each display, with the constraint that the 27 alternative objects appeared once in each position.

In order to designate the relevant stimuli, a pointer appeared just outside the display, indicating one of the nine positions. These pointers were narrow wedges, 69 min. of visual angle in length, which were bright white portions on a flat black painted vinyl card. The pointers were presented simultaneously with the displays for the same exposure duration. Depending upon the condition, there was a single pointer, three pointers indicating adjacent objects, or three pointers indicating three equidistant separated objects on the display. Thus, there were nine different locations for the single and for the three adjacent pointers, and three different locations for the three equidistant pointers. The various pointer locations appeared equally often and in random order within a block of trials.

The displays were constructed and the pointers combined with them in such a way that for a given location of the pointer, all three values of each stimulus variable occurred equally often at all nine display positions. Also, each of the 27 possible objects (i.e., combinations of size, color, and angle) was indicated once by the single pointer and once by each of the three pointers in the multiple-pointer conditions. Three different display-pointer combinations were used in the experiment. The sequence of the displays and pointers within a block of 27 trials was determined by shuffling the stimulus cards before each block.[2]

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[2] It may be noted that the stimuli for the Single-Object condition were an orthogonal combination of the three stimulus variables, but this was not true for the multiple-object

*Procedure*.—Four male students at the University of Illinois served as paid volunteer *S*s. Two of them were graduate students in psychology.

Five main experimental conditions were studied. Four conditions were determined by combining the two object separations of the three-pointer displays with identification of different dimensions or of the same dimension for each object. In an additional condition a single pointer appeared with the display and *S* was required to identify all three dimensions of a single object.

When different dimensions were identified, the order of report was always size–color–angle (e.g., "large blue up" or "medium purple down") for both single- and multiple-object conditions. In the multiple-object conditions, the stimuli were always reported in a clockwise order—i.e., size of the first object, color of the second, and angle of the third. For the three equidistant separated objects, report was begun with the first pointer to the right of the 12 o'clock position. (It is important to note here that the adjacent- and separated-object conditions differed not only in the spatial separation of the three objects, but also in the number and range of spatial positions where each stimulus to be reported could occur. Thus, an anticipatory eye fixation towards the first stimulus, for example, could possibly occur in the separated-objects conditions, though *S*s were instructed against this. This could not occur in the adjacent-objects conditions.)

Each *S* was run for 16 experimental sessions, composed of four replications of the complete set of conditions. Three sessions were run to provide practice and to determine an exposure duration for each *S* which would yield a 75% hit rate for identifying colors under the single-object condition. (Discrimination of colors was more dependent upon exposure duration than were size and angle discriminations at the duration used.) The exposures for the four *S*s were 50, 48, 40, and 29 msec. In some cases the duration was lowered 1 or 2 msec. after a block of four sessions, in order to counteract slight improvements with practice.

Four blocks of 27 trials were run in a session. One of these blocks was always given to the single-object condition, using a single pointer. The other three blocks were all devoted to one of the other four conditions. Whether the same or different dimensions were reported was alternated between each session, and whether the three objects were adjacent or separated was changed after two sessions. For those sessions in which the same dimension of each indicated object was identified, one block of trials was devoted to each of the three dimensions. The order of conditions was counterbalanced between *S*s and replications (four-session blocks). There was a total of 1,728 trials for the single-object conditions, 1,296 for the multiple-object different-dimension conditions, and 432 for each dimension in the same-dimension conditions.

conditions. In the latter case, the values of each dimension occurred equally often, but the 27 possible triplets were randomly sampled for each condition. It was hoped that the random sequence of trials within a block, the number of different conditions, and the use of different pointer-display combinations to provide different samples of the stimulus triplets would eliminate the possibility of artifactual differences between conditions produced by learning of contingencies between dimensions. The results strongly indicate that the slight departure from orthogonality had no effect.

## *Results*

The effects of the experimental conditions upon identification accuracy are shown in Fig. 1 and 2. In Fig. 1, the lower two curves, obtained from the multiple-object conditions, represent the pooled data from both the adjacent and the separated-object conditions. The curve for the same-dimension conditions was obtained from the first size response, the second color, and third angle, in order to compare properly the same- and different-dimension conditions. The data for all three responses in the same-dimension conditions and for both adjacent- and separated-object conditions are presented in Fig. 2.

An analysis of variance of the data from the different-dimension conditions (3 Conditions × 3 Responses × 4 *S*s) showed significant effects due to conditions, $F\ (2, 6) = 89.30$, $p < .01$; order of response, $F\ (2, 6) = 17.14$, $p < .01$; the interaction of conditions with order of response, $F\ (4, 12) =$

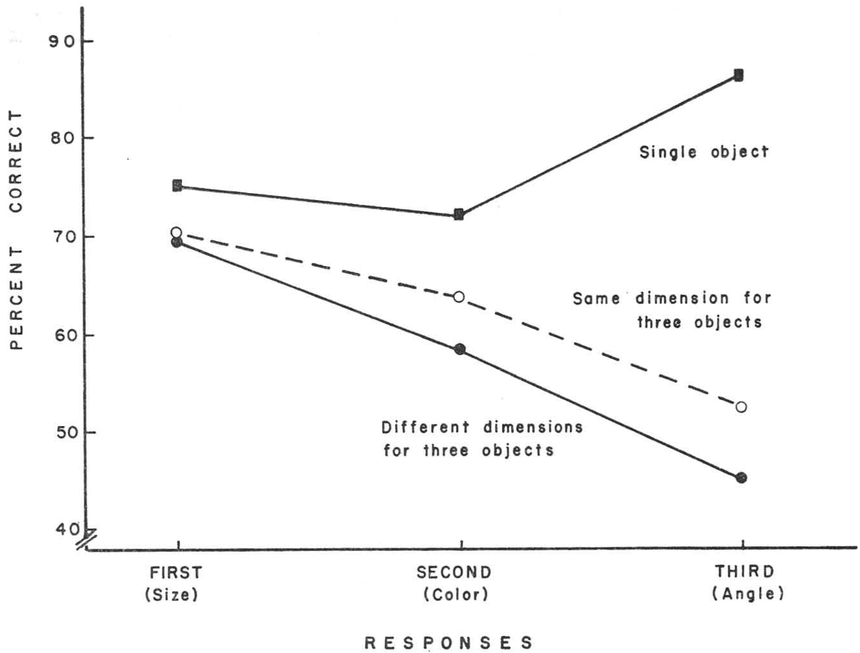


FIG. 1. Percentage of correct identification of three simultaneous stimuli in a complex visual display.

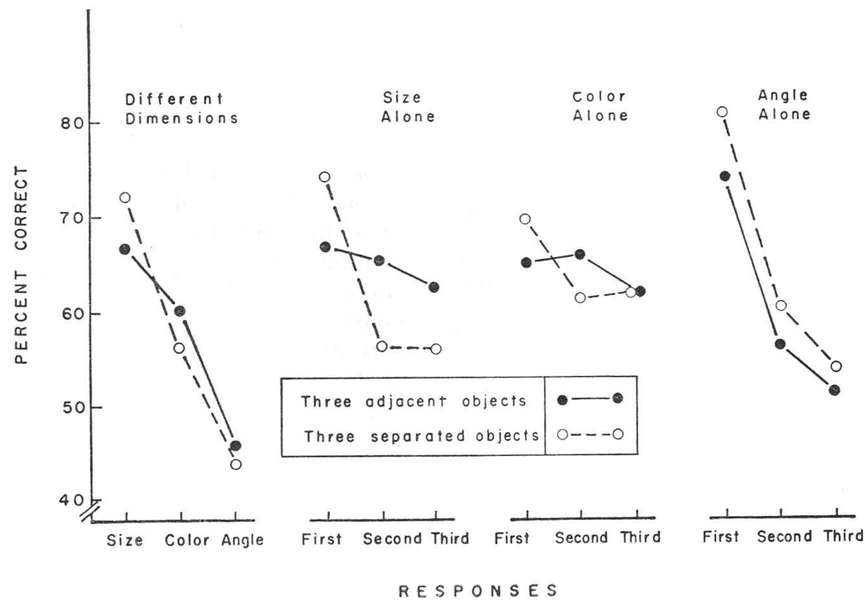


FIG. 2. Percentage of correct identification of a single dimension of three objects in a complex visual display.

31.98, $p < .01$; and *S*s, $F$ (3, 12) = 3.62, $p < .05$. The effect of conditions is due solely to the difference between the single-object and multiple-object conditions, since the overall hit rates for the adjacent and separated objects differed by less than .1%.

A second analysis (2 Dimensions × 2 Separations × 3 Responses × 4 *S*s) compared the same- vs. different-dimension conditions and adjacent- vs. separated-object conditions. Significant effects were found for the same- vs. different-dimension conditions, $F$ (1, 3) = 40.75, $p < .01$; order of response, $F$ (2, 6) = 26.54, $p < .01$; interaction of order of responses with object separation, $F$ (2, 6) = 8.39, $p < .05$; interaction of order of response with *S*s, $F$ (6, 6) = 7.26, $p < .05$; and *S*s, $F$ (3, 6) = 9.41, $p < .05$. The main effect due to separation of the objects is quite small, $F$ (1, 3) = 0.35.

An unexpected finding was the large effect due to the order of report of the three identification responses on the same trial. Moreover, the magnitude of this serial-order effect may be seen from Fig. 2 to differ between dimensions in the same-dimension conditions and between the adjacent- and separated-object conditions. The various dimensions of the same-dimension conditions were compared with respect to variance in hit rate of the three responses. Variance of angle and color, $F$ (6, 6) = 9.82, $p < .01$, did differ significantly; but angle and size, $F$ (6, 6) = 3.48, $p < .10$, and size and color, $F$ (6, 6) = 2.82, $p < .25$, did not quite reach significance. As mentioned above, a significant interaction of order of response with object separation was obtained.

A second major aspect of the data concerns the correlation in accuracy between the three responses made to each display. The relevant data are provided in Table 1, which contains average observed and predicted hit rates for each combination of responses on the same trial, for each condition. The predictions, made for each *S* and condition, are equal to the product of the marginal hit rates for each response taken separately, on the hypothesis that the responses are independent. As may be seen, the observed and predicted values correspond closely; the largest discrepancy is 2.3%, and trends are not apparent for any of the experimental conditions. Thus, the correlation in accuracy of responses on the same trial was approximately zero for all experimental conditions.

TABLE 1

AVERAGE ($n$ = 4) OBSERVED AND PREDICTED PERCENTAGE CORRECT FOR MULTIPLE RESPONSES ON THE SAME TRIAL

| Conditions | Responses | | | |
|---|---|---|---|---|
| | 1+2 | 1+3 | 2+3 | 1+2+3 |
| Different Dimensions | | | | |
| Single Object | | | | |
| Obs. | 54.7 | 66.6 | 63.3 | 48.3 |
| Pred. | 55.0 | 65.6 | 63.0 | 47.7 |
| Adjacent | | | | |
| Obs. | 40.4 | 30.9 | 27.8 | 18.6 |
| Pred. | 40.4 | 30.9 | 27.7 | 18.6 |
| Separated | | | | |
| Obs. | 42.4 | 32.0 | 25.0 | 18.8 |
| Pred. | 41.0 | 31.8 | 25.0 | 18.1 |
| Size Alone | | | | |
| Adjacent | | | | |
| Obs. | 44.0 | 44.2 | 42.1 | 29.9 |
| Pred. | 43.8 | 42.2 | 41.1 | 27.6 |
| Separated | | | | |
| Obs. | 41.0 | 39.6 | 31.0 | 22.2 |
| Pred. | 42.0 | 41.2 | 31.7 | 23.3 |
| Color Alone | | | | |
| Adjacent | | | | |
| Obs. | 44.4 | 40.3 | 40.8 | 27.3 |
| Pred. | 43.1 | 40.4 | 41.0 | 26.7 |
| Separated | | | | |
| Obs. | 41.4 | 44.0 | 36.6 | 25.2 |
| Pred. | 42.6 | 43.3 | 38.0 | 26.4 |
| Angle Alone | | | | |
| Adjacent | | | | |
| Obs. | 41.9 | 38.2 | 28.5 | 21.0 |
| Pred. | 41.9 | 38.3 | 29.0 | 21.6 |
| Separated | | | | |
| Obs. | 52.1 | 44.7 | 32.6 | 28.5 |
| Pred. | 50.1 | 44.1 | 33.1 | 27.6 |

Note.—Predictions are products of the hit rates for each response taken separately, on the hypothesis that these responses are mutually independent.

TABLE 2

PERCENTAGE CORRECT IDENTIFICATION FOR THREE ADJACENT AND THREE NEAR OBJECTS IN EXP. II

| | *S* 1 | | | *S* 2 | | | Average | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| Adjacent | 84.3 | 64.8 | 58.3 | 71.3 | 51.9 | 56.0 | 77.8 | 58.3 | 57.2 |
| Near | 85.2 | 62.0 | 56.0 | 72.7 | 52.3 | 56.0 | 78.9 | 57.2 | 56.0 |

## EXPERIMENT II

An unsettled question relating to the serial-order effect concerns the *spatial separation* of the stimuli. An effect from this variable is predictable from an internal scanning model of visual attention.

Because the separated objects were equidistant, the starting position for identifying the stimuli was always one of the first three positions to the right of 12 o'clock. It was thus possible that an *S* could shift his point of fixation in such a way that the first stimulus fell on more sensitive foveal areas than the second and third. Such anticipatory eye movements have recently been suggested as the basis of earlier reports of perceptual primacy (Ayres, 1966).

The purpose of Exp. II was to examine the serial-order effect for objects which were separated, but not equidistant, so that the first stimulus could occur in any one of the nine display positions and therefore could not be anticipated.

### *Method*

*Pointers.*—An additional set of nine near indicators was constructed like those of Exp. I except that the pointers were moved one position nearer to each other than for the equidistant pointers of the previous experiments (e.g., indicating numbers one, three, and five, of the nine display positions).

*Procedure.*—Two male graduate students in psychology, one of whom had served in Exp. I, served as paid volunteers.

Since the largest serial-order effect had previously been obtained for angles, the three stimuli to be identified in each display were always angles. The adjacent- and near-objects conditions were each run for two blocks of trials in each session, in a counterbalanced order. Each *S* ran four sessions, for a total of 216 trials per condition.

All other materials and procedures were unchanged from Exp. I.

### *Results*

The results of Exp. II are given in Table 2. As may be seen, a large serial-order effect was obtained for the three stimuli, but there was very little difference between the two experimental conditions in the accuracy of each of the responses. Spatial separation per se seems to have no effect on identification of the stimuli in these displays. The previous differences between adjacent and separated objects may most parsimoniously be considered the result of anticipatory eye fixations. The adequacy of a central scanning model of visual attention is doubtful.

## DISCUSSION

The principal finding of this study is that the ability of an *O* to identify a brief visual stimulus may systematically vary under conditions of constant stimulation and response. In particular, the identification of three simultaneous stimuli in a complex display was shown to depend upon the relationship between the stimuli —whether the stimuli were the three dimensions of a single object, the same dimension of three objects, or a different dimension of each of three objects. This finding implies the operation of selective attention in visual perception. Because all stimuli were presented to approximately equally sensitive foveal areas for exposure durations shorter than voluntary eye-movement latencies, this selective process must operate subsequent to reception of the stimuli by the sense organs.

*Independence of simultaneous stimulations and channel capacity of the perceptual system.*—An especially noteworthy finding is that the three responses on the same trial *within* each condition of Exp. I were independently accurate; whereas differences *between* conditions demonstrate that simultaneous stimuli do interact in the process of being identified. These seemingly contradictory results indicate changes in strategy from one condition to another—changes such that for each condition the three relevant stimuli were responded to as a type of *unit,* with three independent parts. Insofar as identification accuracy varied between conditions, these "units" might be considered to have varied in size.

The generalization indicated by this result is that the channel capacity of the perceptual system is not fixed. That is, if there were a fiixed number of stimuli which could be independently perceived within each display, then variations in identification accuracy should reflect the likelihood that some of the stimuli could not be included within the "span" of attention, and then one stimulus should be identified at the expense of another. That this was not found implies that the span of attention is not constant, but varies with respect to the amount and kind of stimulation which is included.

This study thus indicates some modification of previous estimates of the number of items which can be simultaneously perceived (e.g., Eriksen & Lappin, 1967a; Miller, 1956; Schlosberg, 1948). It seems likely that the departure of the present findings stems from the method used here—more complex displays and the use of relationship between stimuli as an independent variable.

These findings also do not agree with those of Shepard (1964) and Lockhead (1966), who suggest a negative correlation in responding to some stimulus dimensions similar to those of this experiment. However, Shepard's data were collected under less restricted viewing and response conditions, and Lockhead's conclusion was based upon data obtained with stimulus dimensions which were redundant rather than orthogonal as in the present experiment.

*Serial-order effect.*—It is tempting to interpret the independence of the three responses to mean that the stimuli were processed by three "parallel channels" in the perceptual system, but the serial order in response accuracy dictates an alternative description. For those conditions which required responses to multiple objects, identification was at some phase based upon *serial processing.*

However, the source of this serial process cannot be specified. Because the serial-order effect is dependent upon the particular stimuli being identified (i.e., does not occur for single objects and differs among the various single dimensions), the serial process is not merely that of the responses themselves, retrieving information from a fading memory trace.[3] This finding, along with that of Montague and Lappin (1966), conflicts with Haber's (1964) interpretation. It is also difficult to attribute the effect to a central scanning process, since Exp. II indicates that spatial separation of the stimuli had no effect. Furthermore, as suggested in the preceding section, the stages of this processing must be adjustable so that their outcomes are independent.

In general, the results of this study challenge the usefulness of the concepts of "channels" and of "serial" and "parallel" processing in visual perception.

*Optimal presentation of stimulus information.*—The data gathered here on the effect of the *similarity* between simultaneous stimuli to be identified bear certain implications for optimal presentation of stimulus information in complex displays. First, the overall superiority and

[3] This same result was obtained more directly in another experiment by instructing *S*s to try to be more accurate on the third response by "attending" to that stimulus first.

lack of a serial-order effect under the single object conditions further generalizes a point which has been urged by Garner (1962), that a perceiver may transmit much more information when dimensions are added to a single stimulus object, as compared with the addition of spatially distinct elements to the display. Second, it was found that the identification of the same stimulus dimensions was superior to identification of different dimensions of three objects. Third, the differential magnitude of the serial-order effect obtained for various stimulus dimensions under the single-dimension conditions indicates that some stimuli are more readily "encoded" by the perceptual system than are others. In particular, color appears to be a psychologically more potent attribute than are form characteristics such as size and angle.

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