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VISUAL PERCEPTION OF STRUCTURED SYMBOLS

A set of psychological experiments was conducted to explore the effects of stimulus structure on visual search processes. Results of the experiments, in which subjects searched for target stimuli among numerous other stimuli that served as distractors in stimulus displays, provide clear indications of interactive effects on visual search time of stimulus structure and the structure of the viewing context. Certain configurations were found that facilitated search and others that impeded search. Specific contexts were identified that influenced the speed with which target stimuli having particular structural characteristics may be found. These findings emphasize the importance of considering such relationships in selecting stimulus configurations for use as symbols in automated displays.

BACKGROUND

One of the important factors that influence how a viewer's attention will be focused on a display of information is the relationship between the form of the displayed information (e.g., text, pictures, symbols, etc.) and properties of the human visual system that drive perceptual processing. This research project was conducted to explore the nature of this relationship for certain symbol structures of the kind often seen in automated displays. Tactical displays like those in shipboard command information centers are typical examples.

Symbols can have different kinds of structure. For instance, several line segments, arcs, dots, or other elements can be put together in different ways to produce different symbols. Some examples are shown in Fig. 1. Different configurations are produced simply by changing the spatial relationships between arcs or line segments on a given line (imagine moving one element toward and past the other).

The nature of the structure of symbols can influence how well they can be detected in a display, discriminated from other symbols without confusion, and identified for their coded content. Symbol structure is defined for aggregations of different types of composite features. In recent years, researchers[1] have identified three types of features that appear to lie on a psychological continuum ranging from "separable" features at one end, through "configural" features, to "integral" features at the other end. The continuum and the feature types have been defined in terms of visual system processes that appear to be used by experimental subjects performing stimulus detection, discrimination, and identification tasks in the presence of manipulations of stimulus structure.

Separable features, such as color and shape of stimuli, each of which is easily identifiable by itself, are very readily distinguishable as individual features of a stimulus; it takes measurable increments of time for combinations of such features to be integrated into whole stimuli by the visual system.

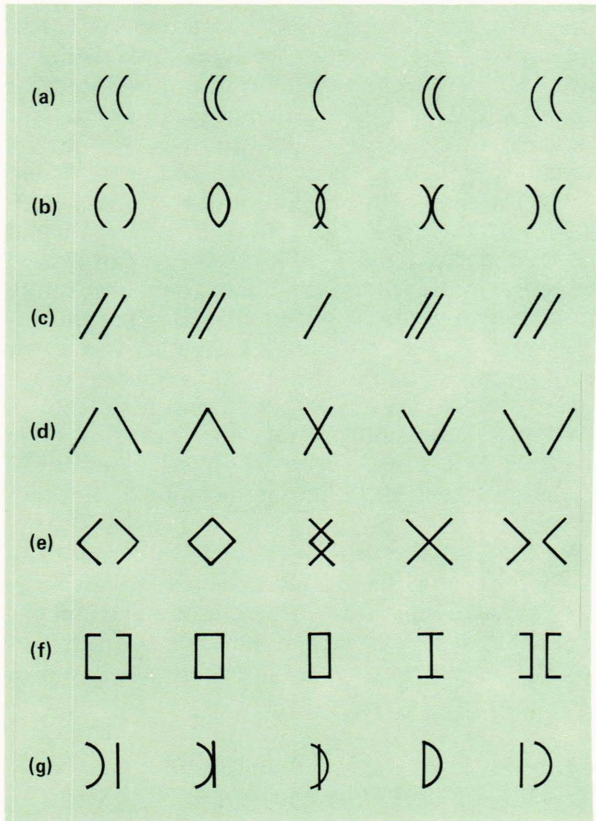

Figure 1 — Examples of stimuli with systematically varied spatial relationships. Configurations in each row are changed (left to right) as one element of the pair is moved toward and past the other.

On the other hand, integral features, such as the physical dimensions of color – hue, lightness, and saturation – must all be present in a stimulus in order for it to be perceived as having the characteristic in question (here, color). Integral features are not individually perceptible in a stimulus; they are processed simultaneously or in parallel by the visual system, as though they were features for purposes of the experimental manipulation but not for the visual processing system.

Between these two poles of the continuum lie configural features, like the ones described below, which are easily discriminable individually, but which may be relatively separable or integral and thus relatively difficult or easy for the visual system to discriminate when they are combined to form various stimulus configurations, like symbols. Our interest has been in the processing of such configural symbols by the human visual system.

Figure 2 shows one of the symbol sets used in our experiments. In this line segment set, the component features of any stimulus are the orientations (right oblique, vertical, and left oblique) of its line segment components. Structural effects are studied by displaying a target symbol together with several distractor symbols. These distractors either are from the same row or the same column as the target ("feature" conditions) or are a combination consisting of one symbol from the target's row and one from its column ("conjunction" conditions). In Fig. 2, for example, for target S (/ |) the feature conditions are stimulus pairs R(//) and T(/\), and V (||) and Y (\|); the conjunction conditions are stimulus pairs R(//) and V (||), R (//) and Y (\|), T (/\), and V (||), and T(/\) and Y (\|). (Only one pair is used at a time.) In the feature conditions, only one feature of the distractor stimuli differs from those of the target stimulus. Therefore, only that feature is relevant to the discrimination of the target in an array of distractors. In the conjunction conditions, both features of the distractor stimuli are relevant, because any one distractor differs from the target on one feature while another distractor differs from the target on its other feature.

We conducted several experiments with such stimuli.[2] Some of the experiments used standard tachistoscope presentation, while others used microcomputer-generated stimuli viewed through the tachistoscope (using it only as a viewing hood). As is shown in Fig. 3, a tachistoscope is a box-like device for displaying visual stimulus materials printed on cards, with mechanical and electronic attachments for changing stimulus cards, illuminating them for specified periods of time, and recording response times of subjects. Subjects searched displays for particular target symbols among distractor symbols, responding as rapidly as possible after determining whether the target symbol was present in or absent from a display. Two sample displays are shown in Fig. 4, both with the same target: (a) shows a feature condition, i.e., the target appears in the context of stimuli requiring discrimination on the basis of only one feature; (b) shows a conjunction condition, i.e., the target appears in the context of stimuli requiring discrimination on the basis of both features.

In all of the experiments, we were looking for evidence of serial or parallel processing of symbol features by the visual system in performance of the speeded visual search task. Subjects were shown displays of stimuli from one of the stimulus sets in arrays of different sizes (4, 8, 16, or 32 stimuli per display), with stimuli in random locations in a 6-by-6 cell matrix. In each set, the target stimulus for a block of trials was present in half the displays. The rest of each array consisted of feature or conjunction

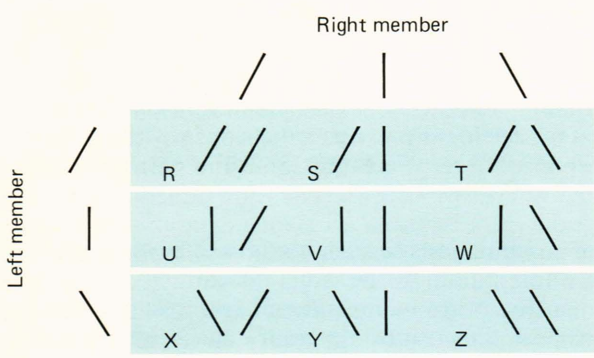

Figure 2 — Line segment stimuli were formed by combining right oblique, vertical, and left oblique components in all possible pairs. Each resulting configuration served as the target stimulus in experiments.

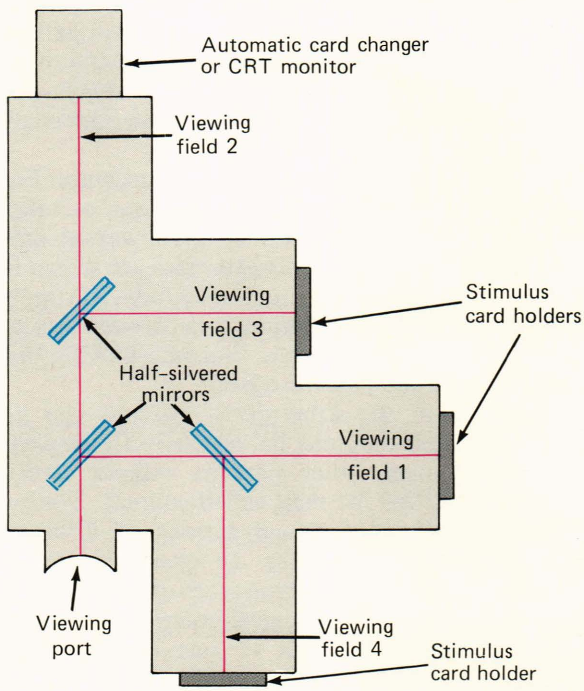

Figure 3 — Schematic view of four-field tachistoscope used in visual search experiments. Only viewing field 2 was used. In some experiments, an automatic stimulus card changer was used to position cards containing stimulus displays. Control apparatus (not shown) automatically changed cards, illuminated displays, and recorded elapsed time (in milliseconds) between display illumination and subjects' pressing of keys on response device. In other experiments, a CRT monitor was mounted in the viewing field. A microcomputer was used to generate and present displays and to record subjects' responses.

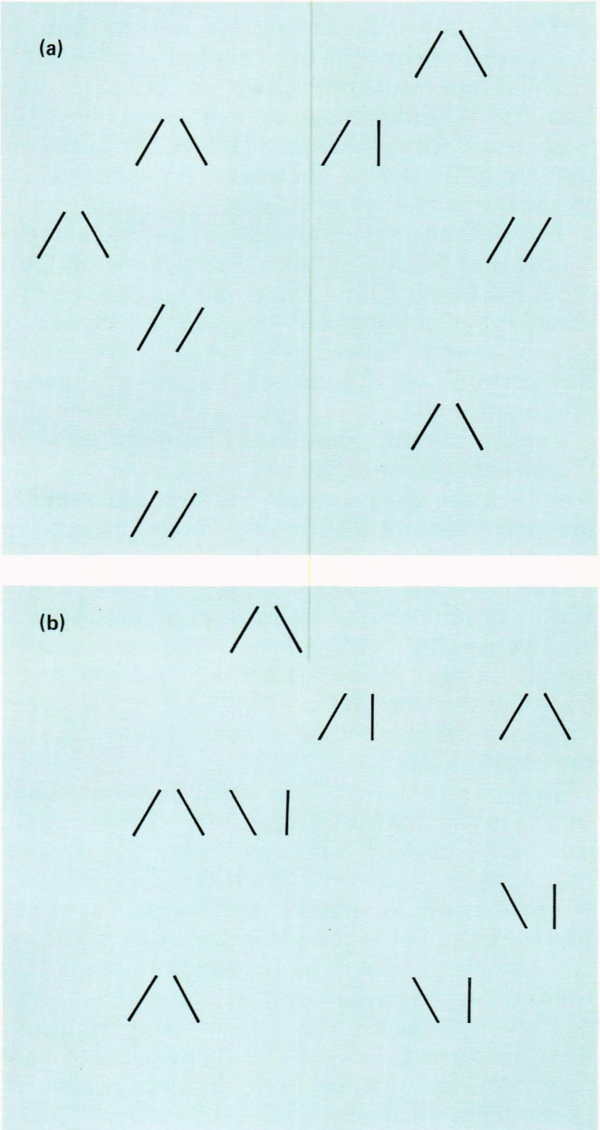

Figure 4 — Sample displays: (a) target S (/ |) among "feature" distractors R (/ /) and T (/\); (b) target S (/ |) among "conjunction" distractors T(/\) and Y (\ |). Each display contained 4, 8, 16, or 32 stimuli, with the target stimulus present in half of the displays of each size. Subjects simply decided as quickly as possible whether the target stimulus was present or not in each display, indicating each decision by pressing a response key. Response times were recorded.

distractor stimuli. A subject's task on each trial was simply to decide whether a particular target stimulus was present in or absent from a display and to register that decision by pressing one of two response keys. Elapsed time was recorded from the initial presentation of a display to the time of the subject's response. Complete data were obtained in this manner for all stimuli in each set.

ANALYSIS

Data analysis for such experiments involves comparing the response times of a number of subjects for the various conditions, using statistical analysis to establish differences among conditions, and referring results to a theoretical psychological model that supports interpretation of the data in terms of serial and parallel information processing by the visual system. In this way, the influence of each kind of distractor on each target symbol in displays of each size may be determined.

The principal reason to determine whether serial or parallel processing is occurring in our tasks is that this distinction appears as a manifestation of two different levels of processing by the human visual system in contemporary psychological theory:[3] preattentive processing and focal attentive processing. Preattentive processing is viewed as an analytical process of extraction of features from the visual stimulus by visual mechanisms that are either genetically predisposed or specially trained to perform such analysis. This feature analysis, which is the earliest level of perceptual processing, takes place very rapidly (within a few hundred milliseconds). It is viewed as (a) proceeding on several different channels simultaneously ("parallel processing"), with different features being processed on independent channels; (b) proceeding automatically, with a stimulus receiving the same preattentive perceptual processing whether or not it is attended at subsequent levels of processing; and (c) being independent of load, i.e., a subject's efficiency in monitoring the environment for signals does not decline as the number of channels to be monitored increases.

Temporally following this preattentive processing, and depending upon it, attention is drawn to one or a set of features of the stimulus for further processing. Such processing is viewed as being under the "attentional control" of the subject in the sense that it can be directed to one or another feature of the stimulus array under consideration. It, too, takes place within a few hundred milliseconds. It is thought (a) to proceed sequentially across feature channels ("serial processing"), with a limited comparison rate; (b) to require the focusing of attention on each relevant feature; and (c) to be strongly dependent on load, i.e., a subject's efficiency in monitoring the environment for signals declines as the number of channels to be monitored increases.

Within this theoretical framework, parallel and serial processing can be distinguished in a set of data by observing patterns of response times for given target stimuli across array sizes. Evidence of parallel or serial processing is present in the slopes of the resulting response curves. Flat functions (and perhaps nonlinearly increasing but decelerating functions) reflect parallel processing of all elements in an array, since the target stimulus can be found in the same amount of time in any size array. Sloping functions, by the same logic, suggest serial search, with larger arrays requiring longer search times for target detection.

RESULTS

Other investigators,[4] using stimuli composed of separable features, have found that for their stimuli – whose component features are perceptually discriminable – feature conditions yield flat response time functions across array sizes, which is indicative of parallel processing; that is, subjects find the target stimulus in the same amount of time regardless of the number of distractors in feature conditions. On the other hand, conjunction conditions yield sloping response time functions indicative of serial processing; that is, it takes subjects incrementally more time to find the target stimulus as array size increases in conjunction conditions.

Our overall results have yielded sloping functions for both feature and conjunction conditions. The slope of the feature condition function relative to that of the conjunction condition function may prove to be a new index of the configurality of sets of stimuli.

The results of our experiments indicate that subjects were sensitive to differences between target stimuli, to differences in sizes of stimulus arrays, and to the contexts provided by the various distractor sets. Data for line segment targets are presented in Fig. 5. In conditions with the target present, response times for targets T (/\), V (| |), and X(\/) were significantly faster than those for targets S (/ |), U (| /), W (|\), and Y (\ |), with intermediate times being recorded for targets R (//) and Z(\\). This may be interpreted to mean that the fastest times were

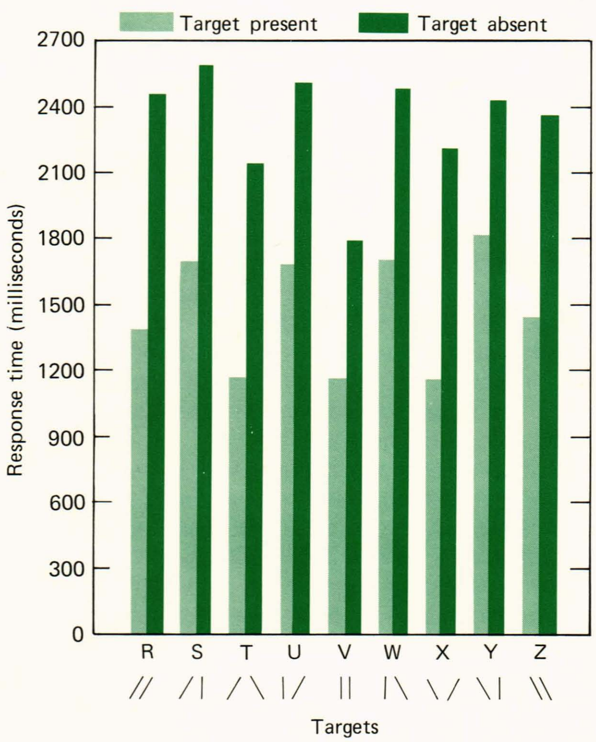

Figure 5 — Response times by target for line segment stimuli presented in CRT displays. Fastest response times were recorded for targets T(/\), V (| |), and X(\/); slowest times were recorded for targets S(/ |), U(| /), W(| \), and Y (\ |); intermediate times were recorded for targets R (/ /) and Z(\\). There was no difference in response times for target conditions when targets were absent from displays.

recorded for stimuli that are symmetrical about the vertical axis; that the slowest times were recorded for stimuli that are asymmetrical about the vertical axis; and that intermediate times were recorded for those stimuli that, while not symmetrical about the vertical axis, comprised pairs of parallel lines. (In conditions with the target absent, there were no significant differences among response times.)

The differences in array sizes produced sloping response time functions; this indicates some degree of serial processing rather than parallel processing in all cases, although slopes vary by target and context. In some instances, there is evidence of nonlinearity of the functions, which is perhaps suggestive of parallel processing.

Context effects appear in the results as effects of the various distractor sets. Since there were two different feature distractor sets and four different conjunction distractor sets for each target, these effects were studied in considerable detail.

One important overall comparison is that between feature conditions and conjunction conditions across all nine targets. Feature distractors produced a less steeply sloping function than did conjunction distractors when the target was present; there was no difference between the two kinds of distractors when the target was absent.

This overall view of the data, however, masks some very interesting effects of the context in which each target appears. First, particular distractor sets introduced response time differences among distractor contexts for all targets except the pair of vertical parallel lines. For every target there was at least one conjunction distractor set for which response times were as fast as or faster than those for a feature distractor set (Fig. 6). This is a surprising result, since more processing should be needed when both features of the stimuli are relevant to target discrimination than when only one feature is relevant. It implies parallel processing that in some cases makes it as easy for the visual system to search for whole configurations among other configurations as it is to discriminate among stimuli on the basis of a single relevant feature.

DISCUSSION

Given such results, why do certain contexts make it easier to find a target than others do? Put another way, what are the characteristics of distractor sets that allow the fastest response times per target?

One possibility is that target-distractor differences that reside on either the left or the right side of the stimuli are responsible for response time differences. If these differences were present, they would be seen only in feature conditions, since all conjunction conditions include a mix of left- and right-sided variation. However, there is no evidence of the presence of such left-right differences in the data for any of these targets.

Inspection of the target-distractor pairings for the various conditions reveals some other factors. Tar-

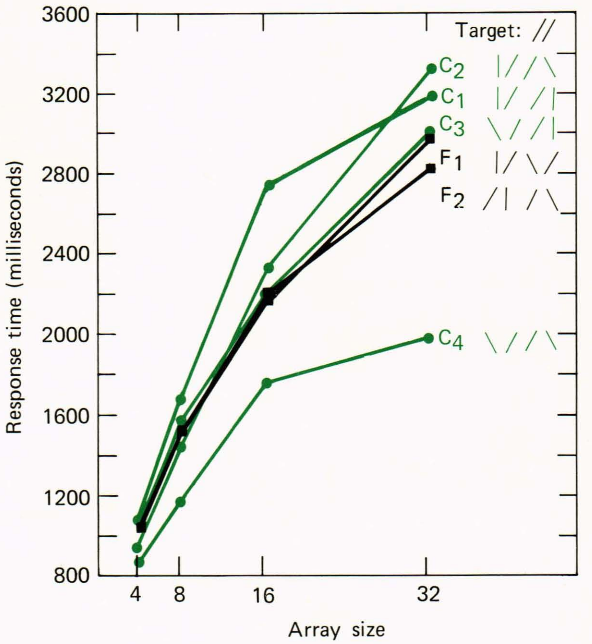

Figure 6 — Response times by array sizes for feature (F) and conjunction (C) conditions for target R (/ /) in CRT presentation. Responses to conjunction condition 4, in which the distractors were stimuli X(\/) and T(/\), were even faster than responses to either of the feature conditions.

gets R (//) and Z (\\), which are mirror images of each other (about either a vertical or a horizontal axis), were both found fastest in the conjunction condition context of stimuli T (/\) and X (\/); that is, these pairs of oblique parallel lines were found most rapidly in the context of line pairs as far from parallel as possible in this set of stimuli. Conversely, targets T (/\) and X (\/), which are mirror images of each other about a horizontal axis, were both found fastest in the conjunction condition context of stimuli R (//) and Z (\\). Thus the presence of pairs of oblique parallel lines facilitated determination of the presence or absence of line pairs as far from parallel as possible. Together, the results for these four targets suggest the reversibility of the target-context relationship for these stimulus configurations.

Looking next at target V (| |), a pair of vertical parallel lines, we find that there are no significant differences among any of the context conditions. That is, it is equally easy to determine the presence or absence of this target stimulus in all of the distractor conditions. This suggests that there is something perceptually special about this stimulus configuration.

The special status of the pair of vertical parallel lines is confirmed by inspection of the remaining four target stimuli, targets S (/ |), U (|/), W(|\), and Y (\ |). For each of these target stimuli, there are two conjunction conditions and one feature condition that include stimulus V (| |) – the pair of vertical parallel lines – as a distractor. For targets S (/ |), U (|/), and Y (\ |), all three of those distractor conditions appear in the context for the fastest response times; for target W (|\), two of the three so appear, with the feature distractor not quite being included. Thus, the vertical parallel line pair not only is just as readily identifiable in any distractor context, but it also facilitates the search for other targets when it is a distractor itself.

The specific contextual relationship between target and distractor stimuli accounts for a substantial part of our experimental results. In particular, we have found that visual search performance can be facilitated or hindered by contextual relationships that only emerge when specific targets and distractors appear together in a display. Thus, although general perceptual factors can explain many of the effects we have observed, these emergent relationships must also be considered when such stimuli are selected for use as symbols in automated displays.

REFERENCES and NOTES

[1] See, e.g., W. R. Garner, *The Processing of Information and Structure,* Lawrence Erlbaum Associates, Potomac, Md. (1974); R. L. Gottwald and W. R. Garner, "Filtering and Condensation Tasks with Integral and Separable Dimensions," *Percept. Psychophys.* **18**, 26-28 (1975); J. R. Pomerantz and W. R. Garner, "Stimulus Configuration in Selective Attention Tasks," *Percept. Psychophys.* **14**, 565-569 (1973).

[2] For a detailed discussion of experiments and theoretical background, see B. W. Hamill and R. A. Virzi, "Effects of Configural Stimulus Structure on Visual Search Processes," Milton S. Eisenhower Research Center Preprint Series No. 90, The Johns Hopkins University Applied Physics Laboratory (Dec 1983).

[3] See, e.g., H. Egeth, "Attention and Preattention," in G. H. Bowser (ed.), *The Psychology of Learning and Motivation,* Vol. 11, Academic Press, New York (1977); H. Egeth, J. Jonides, and S. Wall, "Parallel Processing of Multielement Displays," *Cognitive Psychol.* **3**, 674-698 (1972).

[4] A. M. Treisman and G. Gelade, "A Feature-Integration Theory of Attention," *Cognitive Psychol.* **12**, 97-136 (1980).