Research Report

ON THE ROLE OF SYMMETRY IN VISUAL SEARCH

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Abstract—*It is known that the efficiency of visual search for a target item among distractor items increases when distractors are similar to each other and decreases when target and distractors are similar. Here we show that symmetry relations between targets and distractors can alter search efficiency. When distractors form a background texture symmetrical about a vertical axis, search is easier than when they do not. In contrast, when some distractors are symmetrical with the target, search is more difficult than when they are not. These results suggest (1) that symmetry relations are processed in parallel and can help to distinguish a target from a distracting background and (2) that stimulus similarity can have several components even for a single feature (here, orientation).*

The ability to find a desired target in a distracting background is a central task of vision. It is intuitively clear that the search for such a target becomes easier as the difference between that target item and the background items becomes greater. Further, search is easier if all of the background items cohere into a background texture so that the target can be seen as an interruption of that texture. These intuitions have been experimentally tested with the visual search paradigm. A visual search is generally very efficient if the distractors are homogeneous and if the target differs from the distractors in some basic attribute such as color, orientation, or motion (Treisman & Souther, 1985). The time required to find the target in such a search is largely independent of the number of distracting items. Based on this and other findings, searches for basic features are assumed to proceed with all items processed in parallel.

Feature search becomes less efficient if the target and distractors are made more similar to one another (e.g., Nagy & Sanchez, 1990) and when distractors are less similar to each other (orientation, Moraglia, 1989; Wolfe, Friedman-Hill, Stewart & O'Connell, 1992; color, D'Zmura, 1991; Duncan, 1989). Similarity, in this case, is defined by the distance between stimuli in a sensory space (color space, in the case of Nagy & Sanchez, 1990; angular separation in the orientation experiments). Either of these manipulations of the relations between stimuli can be sufficient to force an apparently serial, item-by-item search through a display at a rate of about 40–60 msec/item (Bergen & Julesz, 1983). These findings can be summarized by saying that the efficiency of visual search *increases* with increasing similarity between distractor items and *decreases* with increasing similarity between the target and the distractors (Duncan & Humphreys, 1989).

The notion that search performance is based on similarity, defined as distance in some sensory (or even physical) space, has an attractive simplicity. However, just as it has proven inadequate in the categorization literature (e.g., Medin, 1989; Tversky, 1977), it turns out to be inadequate in visual search. In this paper, we deal with visual search for orientation. Certainly, the efficiency of search for a target orientation is related to its angular separation from the distractor orientations (Foster & Ward, 1991a, 1991b). Here we show that it is also necessary to consider the symmetry relations among display elements. If background items are symmetrical with each other and the target is not, the symmetrical items seem to form a "good" background texture. Against this background, the target stands out and visual search is facilitated. If target and distractors are symmetrical, search is impeded because the target is more likely to be seen as part of the background texture, a form of camouflage.

Pascal (as cited in Corballis & Beale, 1976) asserted that "symmetry is what you see at a glance." Were he writing today, he might propose that symmetry can be detected "preattentively" (Julesz, 1981; Julesz & Bergen, 1983; Neisser, 1967). This assertion has been supported by the finding of Julesz (1971) that a 40-msec exposure allows perception of symmetry in random dot patterns. If symmetry relationships are processed in parallel, they should have an impact on visual search in the orientation domain. Experiment 1 was designed to give symmetry a chance to aid in visual search.

EXPERIMENT 1

Methods

In each trial, subjects were faced with an array containing distractor items of two orientations. In the *vertical symmetry* condition, these were symmetrical around a vertical axis. (Note that for single line segments, symmetry about a vertical axis is accompanied by symmetry around a horizontal axis, as well.) In the *oblique symmetry* condition, 50 deg was added to each distractor orientation. Thus, the distractors were still symmetrical, but around an axis tilted 50 deg off vertical. Various studies have shown that symmetry is far more salient around a vertical axis than around an oblique axis (Corballis & Roldan, 1975; Goldmeier, 1972; Palmer & Hemenway, 1978). Although the distractors were symmetrical, the display as a whole was not. It consisted of 4, 8, 12, or 16 line segments randomly placed in an irregular 4 × 4 array in an 11.3 by 11.3 deg field with a small central fixation point. There were an equal number of the two distractor orientations. The target, present on 50% of the trials, was of a third orientation. Target and distractor orientations varied from trial to trial, picked at random from a set of 16 possible triplets of orientations (listed in Table 1). Thus, subjects could not look for specific target or distractor orientations or for a particular orientation category like "steep" or "tilted left" (Wolfe et al., 1992). They needed to examine the display and determine whether an item of unique orientation broke the symmetrical texture of the

Table 1. *Stimuli for Experiment 1*

	Vertical Symmetry			Oblique Symmetry		
	target	D1	D2	target	D1	D2
1	0	30	−30	50	80	20
2	−10	40	−40	40	90	10
3	80	50	−50	−50	−80	0
4	90	60	−60	−40	−70	−10
5	50	20	−20	−80	70	30
6	−60	30	−30	−10	80	20
7	70	40	−40	−60	90	10
8	20	50	−50	70	−80	0
9	−30	60	−60	20	−70	−10
10	40	70	−70	90	−60	−20
11	90	30	−30	−40	80	20
12	60	20	−20	−70	70	30
13	30	70	−70	80	−60	−20
14	0	60	−60	50	−70	−10
15	−60	20	−20	−10	70	30
16	−30	70	−70	20	−60	−20

Note: For each condition, there are 16 triplets of 1 target and 2 distractors.

distractors. Sample trials are shown in Figure 1a.

It might have been desirable to have a condition without symmetry, but this is not possible without important changes in other aspects of the experiment. If there are two distractor orientations, those two orientations will *always* be symmetrical about some axis. To break symmetry would require a third distractor orientation. This would make search more difficult by increasing distractor inhomogeneity (Duncan & Humphreys, 1989), making any comparisons problematical. In the present experiment, we rely on the comparison between salient vertical symmetry and far less salient oblique symmetry to reveal the role of symmetry in search.

Stimuli were straight lines 2.0 deg in length and 0.3 deg in width. Stimuli were presented on a standard TV monitor (640 × 480 pixels). Antialiasing techniques were used to eliminate the jaggedness of oblique lines. Displays were controlled by an IBM PC-XT with IBM-YODA graphics.

Ten naive subjects with normal or corrected-to-normal acuity were tested on 330 trials in the vertical and oblique symmetry conditions. The first 30 trials in each block were practice. Order of conditions was pseudorandom across subjects.

Results

The average results are shown in Figure 1b. The two lower curves (solid squares) show target and blank trial reaction times (RTs) for the vertical symmetry case. It is obvious that vertical symmetry produces much faster RTs than oblique symmetry (upper curves, solid circles) [ANOVA main effect of condition: target trials $F(1, 9) = 72.7$, $p < 0.001$, target-absent trials: $F(1, 9) = 23.2$, $p < 0.005$]. For target trials, the task actually becomes easier for larger set sizes [RT × set size slopes significantly less than 0.0 $t(9) = 3.7$, $p < 0.005$]. Target trial slopes for the oblique symmetry condition do not differ significantly from 0.0 [$t(9) = 0.5$, $p > 0.25$]. Error rates (given in Fig. 1 caption) are quite high but do not show evidence of a speed–accuracy trade-off. Slower RTs are accompanied by more errors.

Discussion

These RTs are long relative to those in other, easier search tasks performed in our lab. Orientation search among homogeneous distractors yields RTs of about 500 msec, independent of set size. This is hardly surprising. In this task, subjects do not know the identity of the target or distractors on a given trial. The distractors are heterogeneous and the target has no unique categorical status. All of these factors have been shown to impair search efficiency (Wolfe et al., 1992). Under these circumstances, it is noteworthy that RT, though long, is independent of (or negatively related to) set size, suggesting a difficult but parallel search. Introspectively, subjects appear to be sensitive to the texture created by the distractor elements and detect the target as a disruption of that texture. The faster search in the vertical symmetry condition suggests that the distractors form a better texture when they are symmetrical about a vertical axis than when they are symmetrical about an oblique axis.

This conclusion is bolstered by the negative slopes seen for the target trials in the vertical symmetry condition. If subjects are attempting to see the background as a texture, 16 items make a better texture than 4.

Relatively slow but parallel extraction of properties from a display is not unprecedented. For example, stereoscopic depth supports parallel visual search but often with RTs much longer than those for other basic visual features (Nakayama & Silverman, 1986).

EXPERIMENT 2

Methods

In a second experiment, we use a quite different search paradigm to explore the role of symmetry. Here, we demonstrate that symmetry between targets and distractors can *slow* visual search. Unlike Experiment 1, the target was the same on all trials: a red line tilted 40 deg left of vertical (henceforth −40 deg). There were two conditions. In the *symmetrical* condition, the distractors were green lines of the same −40-deg orientation and red lines that were symmetrical, in relation to the vertical axis, with the target (40 deg). In the *control* condition, distractors were green −40 and red +10 deg, closer in orientation to the target but not vertically symmetrical with it. In both searches targets were standard conjunctions of color and orientation. Set sizes were 1, 4, 8, and 12 items. In all other aspects, the methods were similar to Experiment 1. Achro-

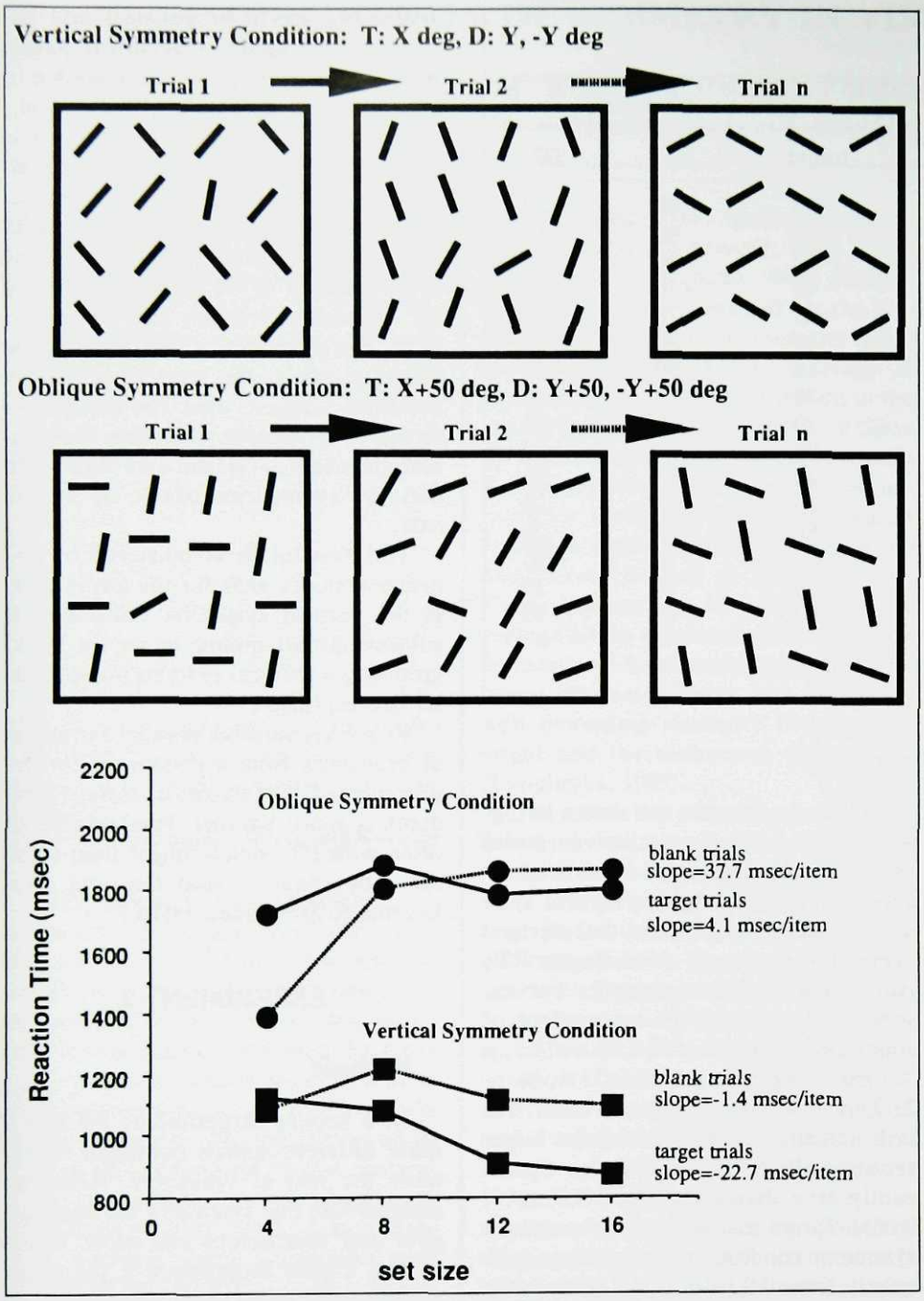

Fig. 1. Sample stimuli and data for Experiment 1. In both conditions, there are two distractor orientations. On half the trials, a third *target* orientation is present. Subjects respond as quickly as possible to the presence or absence of the unique target orientation. Target and distractor orientations vary from trial to trial. It is easier to find the target if the distractors are symmetrical about a vertical axis (lower curves, solid squares) than if they are symmetrical about an oblique axis (upper curves, solid circles). Error rates (set size, vertical sym, oblique sym): (4, 11.4%, 12.4%), (8, 10.6%, 18.2%), (12, 5.9%, 15.5%), (16, 5.1%, 15.4%).

matic examples of the stimuli are shown in Figure 2a.

Results

Results are shown in Figure 2b. Slopes were computed without data from set size 1 because with a single item there is no background and, thus, no symmetry relationship. In Experiment 2, the symmetry of target and one distractor type makes search more difficult. For target trials, overall RTs are faster for the *control* condition than for the *symmetrical* condition [$F(1, 9) = 7.7$, $p < 0.025$] and the slopes are shallower [$t(9) = 2.0$, $p < 0.05$]. For target-absent trials, overall RT is not different across conditions [$F(1, 9) = 1.7$, $p > 0.2$] though slopes of RT × set size functions are shallower in the control condition [$t(9) = 2.5$, $p < 0.02$]. In neither condition do the target-absent and target trial slopes appear to be in the 2:1 ratio predicted by a serial, self-terminating search.[1] As in Experiment 1, error rates (given in Fig. 2 caption) are high but do not show evidence of a speed–accuracy trade-off. Longer RTs are accompanied by more errors.

Discussion

In Experiment 2, symmetry interfered with search efficiency. The symmetry re-

1. It should not be surprising that the orientation X color conjunction search of Experiment 2 does not produce the pattern of results associated with serial, self-terminating search. Though it was originally proposed that all conjunction searches would proceed in a serial fashion (Treisman & Gelade, 1980), subsequent research has made it clear that conjunction search is often more efficient than predicted by a serial model (Dehaene, 1989; Egeth, Virzi, & Garbart, 1984; Nakayama & Silverman, 1986; Quinlan & Humphreys, 1987; Treisman & Sato, 1990; Wolfe, Cave, & Franzel, 1989). We have proposed that attention is "guided" to conjunctions by combining information from parallel, feature-analyzing modules lying earlier in the visual pathway (Cave & Wolfe, 1990; Wolfe & Cave, 1989). Thus, in Experiment 2, a parallel color module can activate all items of the correct color, while an orientation module can activate all items of the correct orientation (though see Wolfe et al., 1992).

The more similar an item is to other items, the less activation it gets (Duncan & Humphreys, 1989). The activations are summed and attention is directed to items in order of their magnitude of activation. In this conjunction search, the item with the highest activation is likely to be the target item, as it has the correct color and orientation. However, since this process, like all neural processes, is degraded by noise, other similar items may have relatively high activations and may compete for attention with the target. Experiment 2 suggests that the symmetry of targets and distractors increases target–distractor similarity and, thus, makes search less efficient.

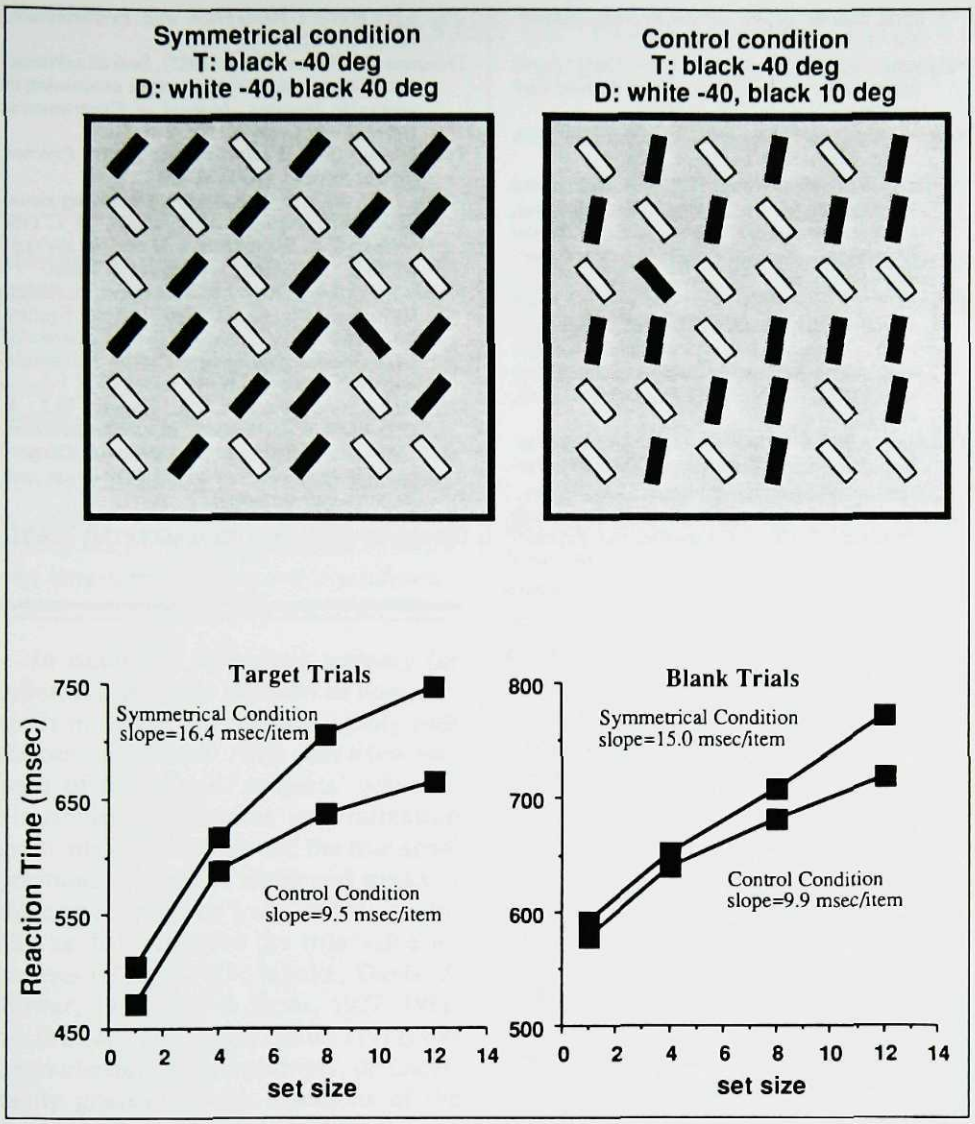

Fig. 2. Sample stimuli and data for Experiment 2. In both conditions, subjects search for a conjunction of a specific color and a specific orientation. In the actual experiment, colors were red and green. Search is easier if the orientation of the target is *not* vertically symmetrical with the orientation of the same color distractor. In this experiment, targets and distractors remain constant throughout a condition. Error rates (set size, vertical sym, control): (1, 4.9%, 3.3%), (4, 4.0%, 2.6%), (8, 5.0%, 4.2%), (12, 5.6%, 4.1%).

lationship between the target and one of the two distractors acted as camouflage for the target. The effects of symmetry are smaller in Experiment 2 than in Experiment 1, but direct comparisons between these two very different search tasks are not of much interest. The search task in Experiment 2 is much easier because targets and distractors are known and remain constant from trial to trial.

The important conclusion to derive from both experiments is that symmetry plays a role in visual search. This obviously complicates any simple understanding of similarity in visual search based on physical or psychophysical *distance* between stimuli. In Experiment 2, search was more efficient when the red distractor differed from the target by 50 deg (−40 to 10) in the control condition than when it differed by 80 deg (−40 to 40) in the symmetrical condition. Taking search efficiency as the operational definition of similarity, we would conclude that 40 and −40 deg are more similar than 10 and −40 even though the difference in orientation between 40 and −40 is obviously greater than the difference between 10 and −40. In Experiment 1, we would conclude that two lines separated by x deg are more similar when they are symmetrical about a vertical axis than about an oblique axis.

This result should not be seen as rendering completely circular the concept of similarity in visual search (i.e., search efficiency defines similarity and similarity determines search efficiency). That would imply that no orderly relationship exists between similarity as defined here and metrics outside the realm of visual search, clearly not the case. Similarity for purposes of search is closely related to distance between stimuli as measured in physical (e.g., orientation) or psychophysical (e.g., color) units. The symmetry results merely remind us that similarity metrics based on a single factor are unlikely to be adequate. In the case of orientation, symmetry as well as angular difference plays a role.

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