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Do intersections serve as basic features in visual search?

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Abstract. The status of 'intersection' as a basic feature in visual search tasks has been controversial. Under some circumstances, a target possessing this attribute (eg a plus) 'pops out' of a display of distractors that lack the attribute (eg Ls). However, those cases may be artifacts of other features such as relative size or number of line terminators. We report two sets of experiments with stimuli intended to control for these factors. Search for the presence or absence of intersections is very inefficient with these stimuli. The results suggest that intersection should not be included among the list of salient features that support efficient search through visual displays.

1 Introduction

In visual search tasks, observers typically look for a target item in a display with some number of distracting items. If reaction time (RT) is measured as a function of the number of items presented (set size), then the slope of the RT × set size function can be taken as a measure of the efficiency of search (or of the cost of adding a distractor). In some cases, search is very efficient. For instance, a red item in a field of green distractors will 'pop out' and will be found time-independent of the number of distractors (Treisman and Gelade 1980). Other stimuli (eg a search for a rotated T among rotated Ls) will be found inefficiently, with each additional L adding 20 – 30 ms to a search where the target is present and about 40 – 60 ms to a search where no target is present (Treisman and Gelade 1980). Note that this inefficiency is present even when stimuli are large enough and spaced widely enough to eliminate the need for eye movements (eg Zelinsky and Sheinberg 1997).

For more than 20 years, researchers have argued over the list of properties that will support efficient search (for reviews, see Wolfe 1998a, 2000). It is uncontroversial to assert that features in some dimensions will support efficient search. Examples include color (Bundesen and Pedersen 1983; Carter 1982; D'Zmura 1991; Farmer and Taylor 1980; Green and Anderson 1956; Moraglia et al 1989; Smith 1962; Van Orden 1993), size (Bilsky et al 1994; Duncan and Humphreys 1992; Müller et al 1995; Quinlan and Humphreys 1987; Stuart 1993; Treisman and Gelade 1980), and orientation (Foster and Ward 1991; Moraglia 1989; Wolfe et al 1992). Other attributes of the visual stimulus have been more problematic. The form or shape of items has posed a particular problem.

It is clear that it is easy to find some shapes among other shapes (eg Beck 1966a; Cohen and Ivry 1991; Donderi and Zelnicker 1969; Isenberg et al 1990; Quinlan and Humphreys 1987; Stefurak and Boynton 1986; Theeuwes and Kooi 1994; Tiana et al 1989; Tsal and Lavie 1988). However, it has not been made clear what shape 'features' might be available to support efficient search. It is not even clear if there are multiple featural dimensions within a general term like 'shape' or 'form'.

Good evidence exists for the featural status of line termination (Bergen and Julesz 1983; Julesz and Bergen 1983; Treisman and Gormican 1988). For example, search for a C among Os is efficient (Treisman and Gormican 1988). It is not obvious whether the relevant features are the terminators on the C or the closure of the O (Elder and Zucker 1994). Chen has argued for a topological account in which Os are in a different category (having 'holes') than Cs (Chen 1982; Chen and Zhou 1997).

In this paper, we re-examined the status of another candidate shape feature, line intersection. Intersection has been proposed as a feature on the basis of search data obtained with stimuli like those shown in figure 1. A plus is easily found amidst Ls composed of the same vertical and horizontal lines (Bergen and Julesz 1983). Moreover, a region of plusses is readily segmented from a background of Ls (Beck 1966a, 1966b; Bergen and Julesz 1983). Over the years, there has been some controversy about the reasons for this efficient search and immediate texture segmentation. Treisman and Gormican (1988) found fairly inefficient search for a plus among the line segments composing the plus. Spatial-frequency filtering can disrupt the easy discrimination of plusses and Ls (Bergen and Adelson 1988; but see Julesz and Krose 1988). Nothdurft (1993) found that masking by spatially bandpass stimuli differentially affected texture segmentation and the identification of stimuli as plusses or Ls. He argued that the texture segmentation was not based on an intersection feature. 'Effortless' texture segmentation and 'pop-out' in visual search tasks are not the same thing (Wolfe 1992). However, in the search for basic features, it is an encouraging sign if a property supports both texture segmentation and efficient search. On the other hand, Kimchi (1994) argued for a role for configural properties like intersection in the assessment of the global/local figures used to produce Navon's (1977) 'global precedence' effect.

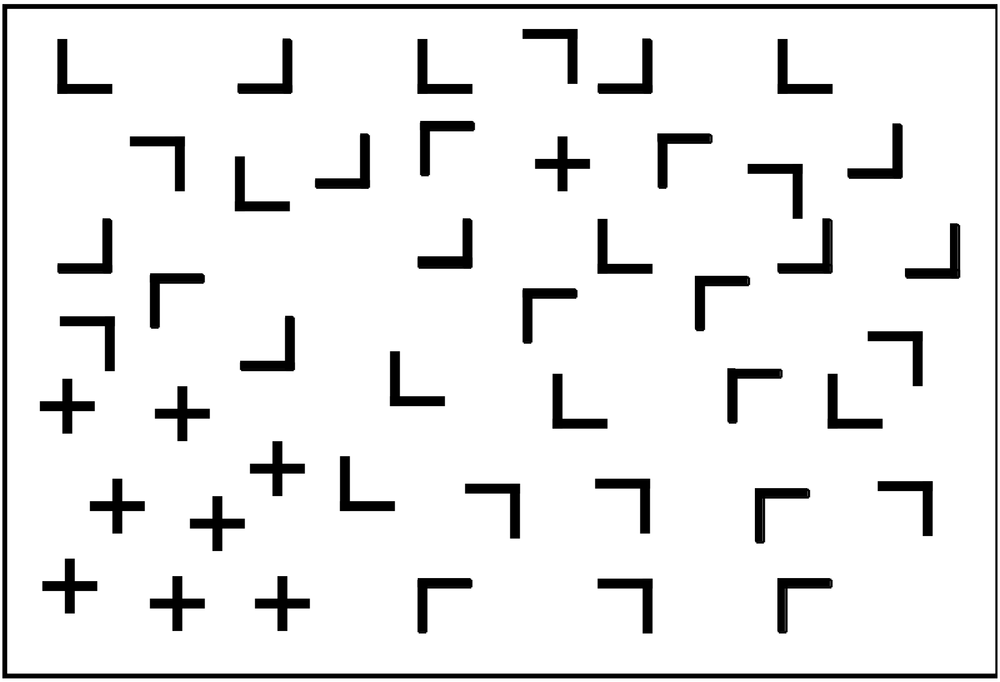


Figure 1. There is no doubt that it is easy to find a plus or a region of plusses among Ls. Does this mean that line intersection is a basic feature in visual search?

Is intersection a feature that supports efficient visual search? The answer is unclear in part because research on the status of intersections has suffered from a lack of variety in the choice of stimuli. Plusses differ from Ls in the presence of an intersection. However, there are other confounding differences that complicate analysis. Plusses have four line terminators while Ls have two. As noted above, line termination seems to function as a feature, and search for the item with *more* of a feature can be very efficient (Taylor and Badcock 1988; Wolfe 2001). Plusses are radially symmetric while Ls are not (Olivers and van der Helm 1998; Wolfe and Friedman-Hill 1992). Plusses look smaller than Ls when their vertical and horizontal segments are the same length. This difference in 'blob' size may be the basis for a number of the filtering and masking effects. Accordingly, our goal in the present paper is to revisit the role of intersection in visual search with the use of a new set of stimuli.

2 Experiment 1

2.1 *Stimuli*

In experiment 1, we created intersection and non-intersection stimuli that were designed to minimize issues of line termination, symmetry, and size. These are shown in figure 2.

The basic intersection stimulus was a cross (2a)—no longer radially symmetric, though it is symmetric about one axis. Rather than thinking of this as the intersection of a vertical and a horizontal line, it can be considered to be composed of four pieces: a smaller and a larger vertical segment and two horizontal segments of equal size. Shifting one of the horizontal segments (2b) creates the non-intersection objects (2c). It can be decomposed into the same four segments. It has the same four line terminators. It lacks an intersection, having instead two T-junctions. Rotating and reflecting 2a and 2c yields four intersection stimuli (2d) and four non-intersection stimuli (2e).

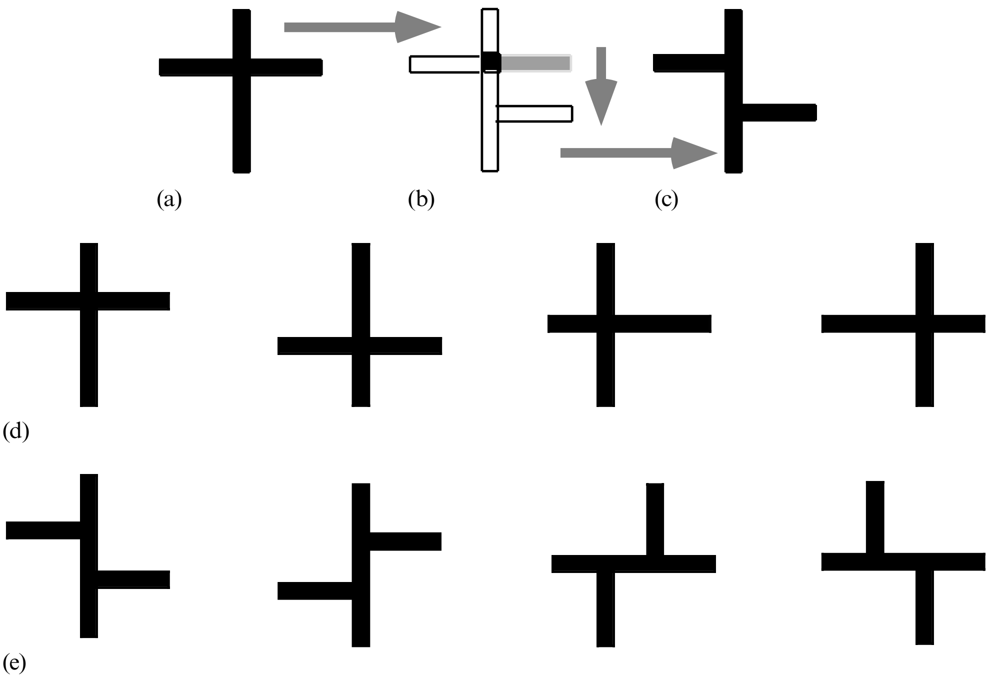


Figure 2. Stimuli with and without intersection used in experiment 1.

Plusses, Ts, and Ls were created by using horizontal and vertical line segments of equal length for control experiments (see below).

At a viewing distance of 57.4 cm, a 3×3 element stimulus array subtended a 20.5 deg $\times$ 20.5 deg square centered on the screen. Each item fit within a 5.5 deg $\times$ 5.5 deg area and was displayed in black against a white screen background. Target and distractor items were randomly presented in one of four orientations: vertical upright (0°), upside-down (180°), horizontal to the left (90°), or to the right (270°).

2.2 *Subjects*

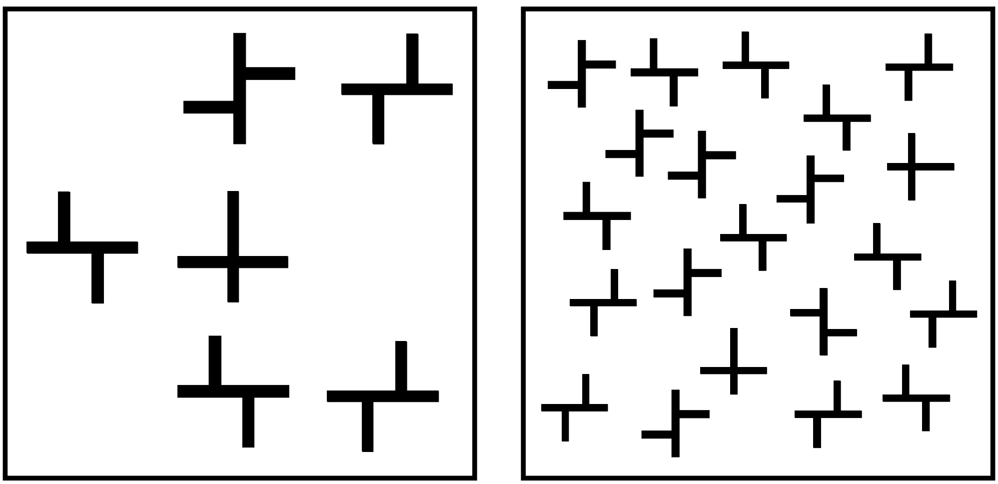
Thirteen naïve observers between the ages of 18 and 55 years served as subjects. Data for three subjects were discarded because of failure to complete the task. Each observer passed the Ishihara test for color blindness and had 20/25 corrected vision or better. All gave informed consent and were paid for their time.

2.3 *Methods*

Data were collected from each subject for six different search tasks. Four of these were control conditions intended to replicate standard search results. Plusses among Ls and Ls among plusses should replicate the standard finding of efficient search for stimuli of this sort. Ts among Ls, and Ls among Ts provide a benchmark for 'inefficient' search. The critical conditions present our intersecting 'cross' stimuli among stimuli without intersection and vice versa. The order in which these six conditions were presented was counterbalanced across subjects. Each block consisted of 30 practice and 300 test trials.

Before the start of each block, subjects were told what the target and distractors would be. On each trial, items were presented at 3, 6, or 9 randomly chosen loci within the array. Set size, positions of target and distractors, and the presence or absence of the target item were random across trials.

At the beginning of each trial, a tone was sounded as the stimuli appeared. Search stimuli remained visible until the subject responded by pressing either a "yes" key if the target was detected or a "no" key if not. Feedback was provided after each trial in the form of text on the screen and a beep if the response was incorrect. There was an intertrial interval of 400 ms. Exactly half of the trials included a target. Subjects were instructed to respond as quickly as possible while minimizing errors. Figure 3a shows a demonstration version of the search for the new intersection stimuli. A larger set size is used in figure 3b, which contains two intersection targets in order to give the reader a feeling for the difficulty of the task.



(a) (b)

Figure 3. Find the 'cross' stimuli—the items with the putative intersection feature. (a) A typical trial for the intersection search condition of experiment 1. (b) The same search in a set size much larger than those used in this study. This permits the reader to gain an intuitive feel for the difficulty of the task.

2.4 *Results*

As will be intuitively clear from figure 3, the new intersection stimuli do not support efficient search. Figure 4 illustrates the average reaction time against set size for all ten subjects for each condition. Results for the plus among L and L among plus search

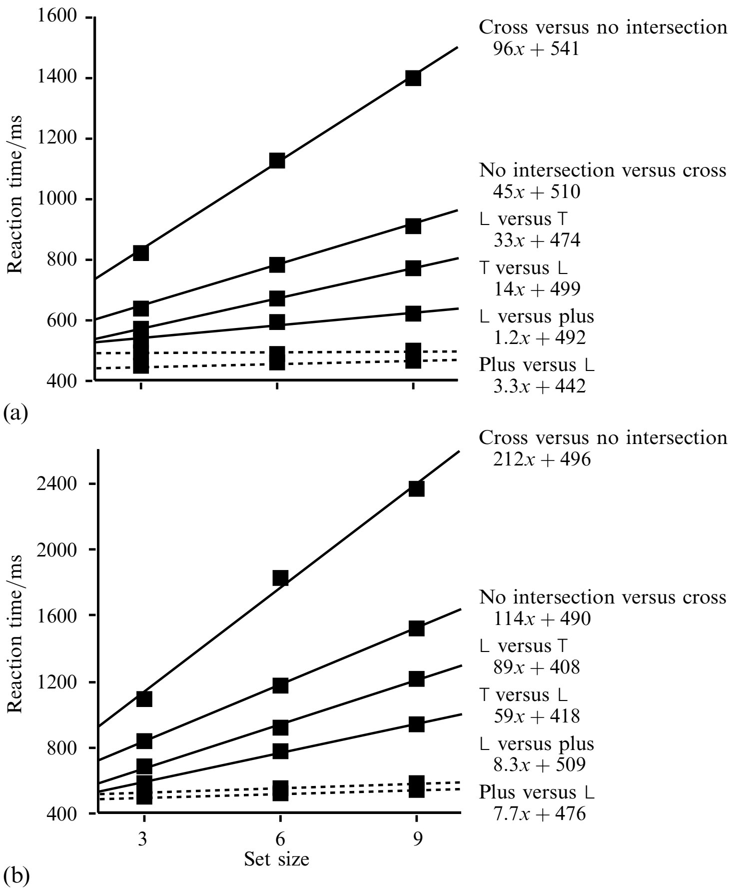


Figure 4. Reaction time plotted against set size for (a) target-present trials and (b) target-absent trials. Results and the best-fitting linear regression lines are shown for each of the six conditions of experiment 1. Condition labels give slopes and intercepts.

replicate the standard finding that led to the idea that intersection was a feature. Searches are very efficient. Results for the T among L and L among T tasks produce typical inefficient search with slopes of 14 and 33 ms/item, respectively, on the target-present trials and target-absent slopes that are more than twice that steep (see Wolfe 1998b). In contrast, the new stimuli produced slopes of 96 ms/item when the intersection stimuli were the targets and 45 ms/item when the intersection stimuli were the distractors. This is not only less efficient than the plus and L results; it is less efficient than the inefficient T and L results. Error rates are given in table 1.

Table 1. Error rates for experiment 1.

Condition	Misses/%	False alarms/%
Plus versus L	1.7	0.7
L versus plus	1.5	0.5
T versus L	1.3	0.6
L versus T	4	0.6
Cross versus no intersection	6.5	0.3
No intersection versus cross	2.6	0.5

It seems almost superfluous to note that these results are statistically reliable. An ANOVA on the target-present slopes reveals a main effect of condition ($F_{5,9} = 57.462$, $p < 0.0001$). A posteriori tests show that slopes for the new stimuli are significantly steeper than those for the traditional plus and L stimulus ($p < 0.0001$) and also steeper than the inefficient T versus L slopes ($p < 0.0001$). The sole exception is that the search for the non-intersection targets was not significantly less efficient than the search for an L ($p < 0.09$). Similar results were found for target-absent trials.

There were reliable search asymmetries in the data (Treisman and Gormican 1988; Treisman and Souther 1985) with search for a T among Ls being reliably more efficient than for an L among Ts (paired t-test on slopes, $t_9 = 2.482$, $p < 0.035$) and search for the non-intersection target being more efficient than search for the cross target ($t_9 = 6.628$, $p < 0.0001$). Similar results were found for target-absent trials.

While not directly relevant to the topic of this paper, the asymmetry in the T versus L searches is interesting. Our subjects found it easier to find a T among Ls than vice versa. This may reflect the presence of an extra line terminator on a T. More of a feature is generally easier to find than less.

2.5 *Discussion and control experiments*

2.5.1 *Eye movement controls.* One of the hallmarks of a basic feature in visual search is that it can be presented in a number of ways and still produce efficient search. Thus, for example, orientation is a basic feature whether it is defined by texture, luminance, color, etc (Cavanagh et al 1990). Similarly, almost any moving stimulus 'pops out' from amidst any set of stationary stimuli. In experiment 1, a perfectly clear intersection is very hard to find amidst non-intersection distractors. A second hallmark of a feature in visual search is that the presence of the feature is easier to detect than its absence (Treisman and Gormican 1988; Treisman and Souther 1985). In experiment 1, the data go in the other direction. While both searches are inefficient, the target without the intersection is easier to find than the target with the intersection.

Indeed, the new stimuli produce slopes that are so steep that one worries about an eye-movement artifact. Any search can be made to be extremely inefficient if the stimuli are designed so as to require subjects to fixate each stimulus or group of stimuli. To eliminate this explanation for the present results, ten subjects performed an identification task on briefly flashed presentations of the new intersection stimuli. On each trial, subjects saw one item: either the cross/intersection stimulus or the non-intersection stimulus. It was flashed in one of the nine stimulus locations used in experiment 1. Stimulus position varied randomly from trial to trial. The stimulus was present for 150 ms, a time too brief to permit subjects to make a voluntary fixating eye movement. Stimuli and other conditions were otherwise identical to those of experiment 1. The measure of interest in this case is accuracy. Under these circumstances, subjects were 83% correct showing that they could reliably identify the stimuli without the need to fixate them.

In a second replication of experiment 1, set size was reduced to 1, 2, or 3 items, and items were enlarged. Each stimulus fit within a 9.5 deg $\times$ 9.5 deg area in a 2×2 element array. Observers were told to identify the presence or absence of the cross/intersection stimulus among non-intersection distractors. Reaction times for search among these large, uncrowded items are similar to those for the smaller stimuli of experiment 1 (figure 5).

2.5.2 *Similarity controls.* Perhaps similarity between targets and distractors accounts for the difficulty of search with the stimuli of experiment 1. It is well known that search slopes increase as target–distractor similarity increases and as distractor–distractor similarity decreases (Duncan and Humphreys 1989). Indeed, the stimuli of experiment 1 were created so that targets and distractors would be similar in size, number of

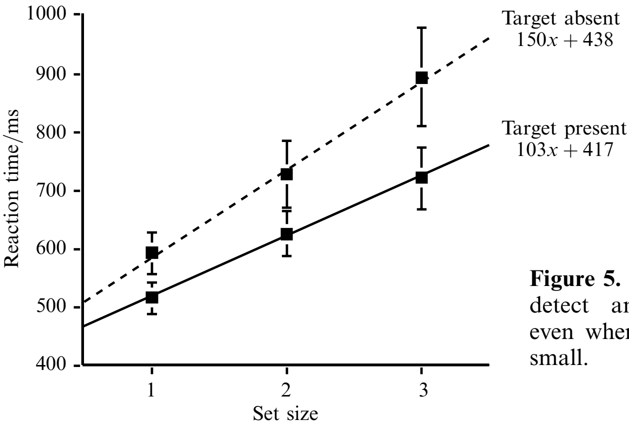


Figure 5. Intersection stimuli are difficult to detect among non-intersection distractors even when items are large and set sizes are small.

line terminators, and every other feature *except* intersection. Moreover, distractors are presented in different orientations, decreasing distractor – distractor similarity (Duncan and Humphreys 1989). Of course, if intersection was a convincing preattentive feature, its presence should—by definition—greatly reduce any target – distractor similarity. Consider that targets of one color can be readily found among distractors of another, even if the stimulus items are identical in every other way. Still, in the present case, it might be imagined that 'intersection' is an aspect of form, and the targets and distractors are otherwise fairly similar in form. In order to address this issue, observers were presented with the stimuli shown in figure 6. These stimuli are identical save for two minor changes. A pixel by pixel comparison would find these stimuli to be more similar than the intersection and non-intersection stimuli of the main experiment. Of course, by splitting the item in figure 6a into three pieces, we expected to find efficient search for this segmented target (figure 6b) among the intact distractors (figure 6a). The task was to detect the presence or absence of the segmented stimulus among the original non-intersection stimuli. All other aspects of the experiment were equivalent to those in experiment 1. Ten observers were tested. Observers produced the expected efficient search for these items. The average slope was 1.8 ms/item when the target was present, and 5.9 ms/item when the target was absent.

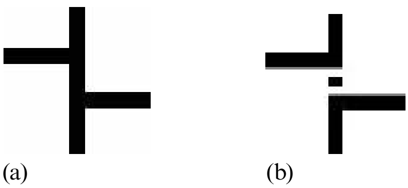


Figure 6. Stimuli for the similarity control experiment. The original non-intersection stimulus is shown in (a); deletion of a few black pixels produced (b).

In addition to search efficiency and asymmetry, a typical feature will support easy texture segmentation. In figure 7, there is a 4×2 item region composed of intersection stimuli among non-intersection stimuli. It is clear that this region does not effortlessly segment from the non-intersection background.

In sum, the results of experiment 1 argue against the status of intersection as a feature. However, before striking intersection from the list of candidate features, it would be desirable to have some converging evidence obtained with a different set of stimuli. Perhaps more of an intersection feature would be easier to find. In experiment 2, we asked subjects to detect a target with many intersections among distractors with no intersections.

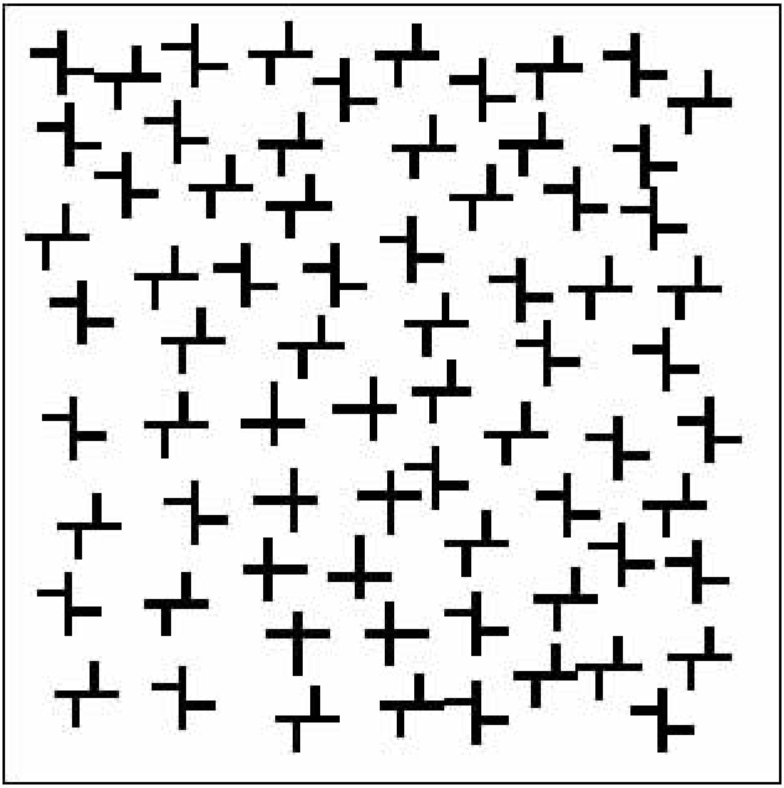


Figure 7. It is difficult to distinguish the area of crosses embedded within this array of non-intersecting items.

3 Experiment 2

3.1 *Methods and stimuli*

The stimuli for experiment 2 are shown in figure 8.

In experiment 2, subjects discriminated between squares containing multiple intersections among squares without intersections (or vice versa); these 'brickwall' stimuli are shown in figure 8a. In control conditions, as shown in 8b, subjects could be asked to search for line terminators among non-terminator stimuli (or vice versa). Stimuli were designed to keep target and distractor differences to a minimum while retaining the differences in either line termination or intersection. Individual items subtended 5.5 deg × 5.5 deg at the 57.4 cm viewing distance. All other aspects of the stimuli and the procedure were identical to those in experiment 1. Ten subjects were tested.

3.2 *Results*

Figure 9 shows the average RT data as a function of set size for all subjects. Confirming introspection (see figure 8), search for the target with six intersections among distractors with no intersections is not efficient (figure 8a). It is somewhat easier to find the target with no intersections (but not significantly, paired $t_9 = 1.028$, $p < 0.34$). Search for line terminators (figure 8b) produced reasonably efficient slopes of 8 ms/item, while the more difficult task of search for the absence of terminators produced a significantly steeper average slope of 47 ms/item. This typical search asymmetry was significant (paired $t_9 = 5.412$, $p < 0.0004$). Error rates are shown in table 2.

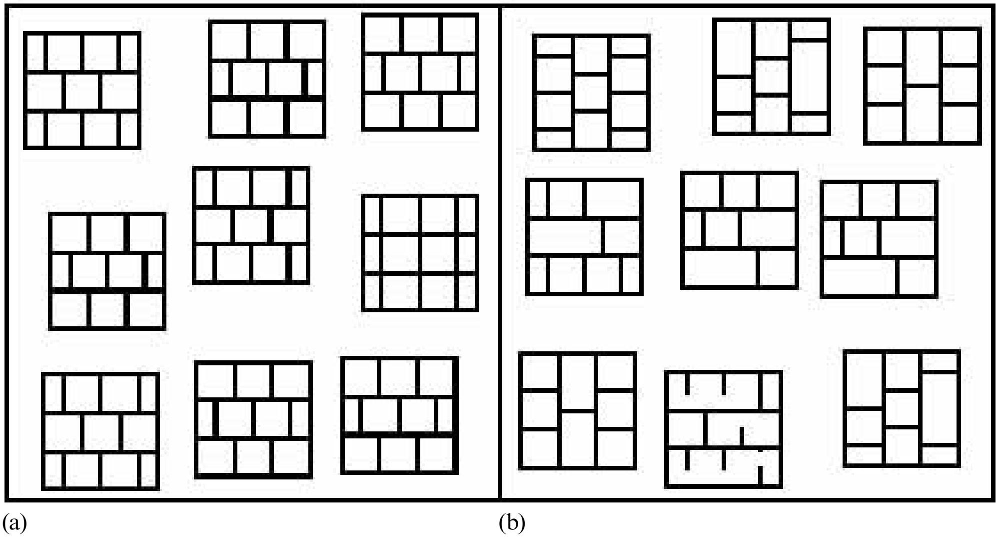


Figure 8. Sample stimuli from experiment 2. Subjects could be asked to look for (a) intersections or their absence, or (b) for terminators or their absence.

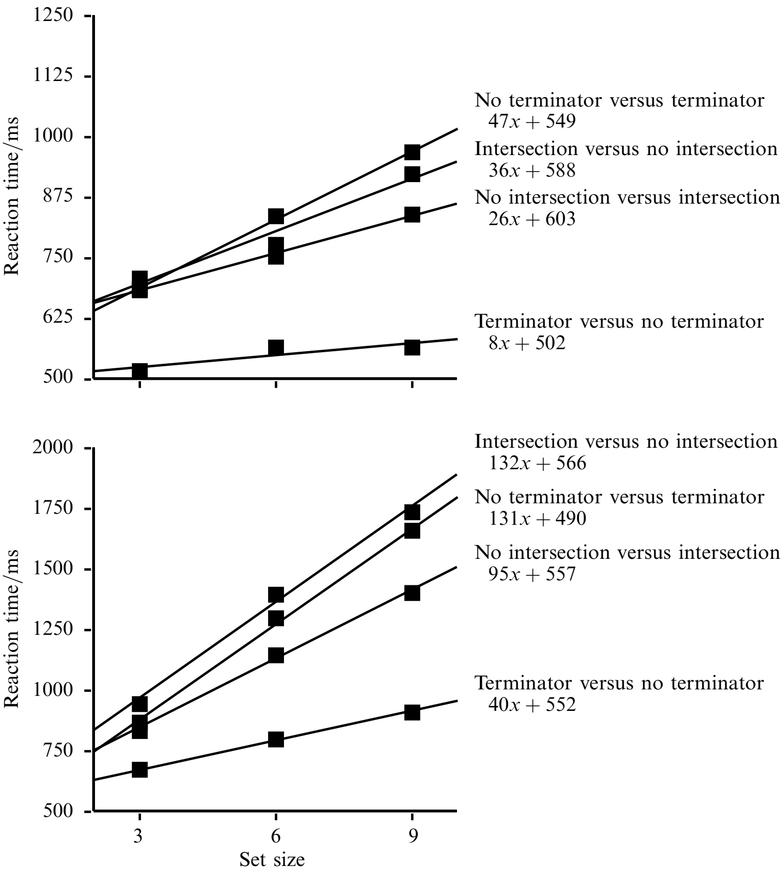


Figure 9. Reaction time × set size results for the four conditions of experiment 2.

Table 2. Error rates for experiment 2.

Target	Misses/%	False alarms/%
Intersections	2.0	0.8
No intersections	2.0	0.7
Terminators	1.1	0.6
No terminators	2.4	0.8

3.3 *Discussion*

The results of experiment 2 do not support the argument that intersection serves as a basic feature in visual search. In this case, a stimulus with multiple intersections failed to be found efficiently among distractors with no intersections. The data from the terminator version of the experiment can be used to demonstrate that stimuli of this sort can produce reasonably efficient feature search. The presence of line termination was readily detected. In keeping with the typical results for feature search, the absence of that feature was more difficult to detect. Thus, these results replicate the well-established finding that terminators serve as basic features in visual search while undermining the claims of intersection to similar status.

4 Conclusions

Some researchers have questioned the entire enterprise of cataloging 'preattentive' features (DiLollo et al 2001; Nakayama and Joseph 1998), but this seems to be an unfortunate case of throwing out a useful baby with the theoretical bath water. The primary objection of the opponents of preattentive features is to the notion of a separate 'preattentive' stage of visual processing (Neisser 1967; Treisman and Gelade 1980). This is not the place for an extended discussion of the usefulness of the preattentive/attentive distinction, though it is worth noting that the idea that you can direct attention to an object implies that there was a time prior to the time when you attended to that object. If any visual processing occurs during that time, it might reasonably be called preattentive without assuming other theoretical entanglements.

Even if one completely abandoned the notion of preattentive processing, the effort to define basic features in visual search would be worthwhile. It is beyond doubt that search for some targets among some distractors can be accomplished in a time that is essentially independent of the number of distractors. It is equally clear that not all stimulus attributes can support this type of efficient search—even if those attributes are quite salient (eg faces—Nothdurft 1993; Purcell et al 1996; Suzuki and Cavanagh 1995; but see, perhaps, Eastwood et al 2001). Therefore, it seems reasonable to ask what the set of basic features might be and to suppose that the set is not arbitrary. If we knew the set, we might better understand the earlier stages of visual processing. The results of the experiments presented here lead us to the conclusion that 'intersection' should not be on this list of basic features.

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