Does previewing one stimulus feature help conjunction search?

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Abstract. We examined the effects of previewing one aspect of a search display, in order to determine what subset of display information is most useful as a prelude to a search task. Observers were asked to indicate the presence or absence of a known target, in a conjunction search where the target was defined by the combination of colour and orientation (a yellow horizontal line presented among yellow vertical and pink horizontal distractors). In the colour preview condition of experiment 1, observers were first shown a 1 s preview of the locations and colours of the search items before the actual search set was presented. That is, search items first appeared as yellow and pink squares for 1 s, which each then turned into yellow and pink oriented lines (in the same locations) which comprised the display to be searched. In the orientation preview condition, observers were first shown a 1 s preview of the locations and orientations of the search items before the actual search display was presented. These two conditions were compared to a control condition consisting of standard conjunction search without any preview display. There was no effect of colour preview; there was a marginal effect of orientation preview, but in the opposite direction from what was expected—reaction time increased for orientation preview searches. In experiment 2 these previews were compared to two spatial cueing conditions; in this experiment the colour preview did provide a small amount of help. Finally, in experiment 3 both previews were presented in succession, and increased facilitation was found, in particular when the colour preview preceded the orientation preview. These findings are discussed in relation to the literature, in particular the Guided Search model (Wolfe et al 1989 Journal of Experimental Psychology: Human Perception and Performance 15 419–433; Wolfe 1994 Psychonomic Bulletin & Review 1 202–238).

1 Introduction
Imagine an airline pilot in distress, who has a fraction of a second to scan a complicated instrument panel in order to respond quickly enough to avoid a problem, or consider a distracted motorist about to hit a pedestrian. Our perceptual and cognitive resources are limited so, when confronted with a complex display, our visual systems must quickly determine what portions are important enough to merit the resources required for full processing and appropriate response. Because early selection mechanisms affect virtually all visual processing, researchers use a variety of tasks to try to understand these mechanisms.

Researchers sometimes present observers with a search task, where a pre-specified target must be detected (or identified). In feature search, the target item differs from distractors (other items) on the basis of just one feature (such as orientation or colour). In conjunction search, two features (eg both orientation and colour) need to be examined in order to determine the presence or absence of the target (Treisman and Gelade 1980). Feature-integration theory (Treisman and Gelade 1980) originally suggested that conjunction search occurs in two stages. According to this model, the first stage of visual search is a parallel mechanism where information about one single feature dimension—such as colour, size, or orientation—can help in the search; each type of feature is represented by a separate feature map in the brain. The second stage of the model is a serial mechanism. Conjunction search requires this stage of processing; each item must be considered in turn to determine whether it satisfies each required feature.
In general, search time is longer for serial search than for parallel search. In addition, set size has a much larger effect on response time for serial search than for parallel search: response time for feature search is relatively independent of set size (it is often described as ‘efficient’), but for conjunction search response time increases with set size (ie it is ‘inefficient’; see Treisman and Gelade 1980).

An alternative approach to the feature-integration model was proposed by Wolfe et al (1989), who presented data which suggested that serial search can be guided by information from the parallel stage. A series of nine experiments provided results that were not consistent with the feature-integration model: conjunction search was performed more quickly than seemed possible with a purely serial mechanism. Wolfe et al (1989) proposed a modification of the feature-integration model to account for this surprising efficiency of conjunction search. This model also consisted of a first, parallel stage of feature maps, and a second, serial stage. Each feature of an object (eg its colour or orientation) excites the spatial location of the object in the relevant feature map to the extent that the object matches the known target features. In conjunction search, where two feature maps are relevant, the spatial location which exhibits the greatest overall amount of excitement should be that of the conjunction target, because it is doubly stimulated for having both the correct colour and the correct orientation. The second, serial stage of processing would be likely to visit that doubly stimulated location relatively early in processing (thus being ‘guided’ by the different feature maps in the first, parallel stage); this guidance would tend to increase search efficiency. Further work has extended the initial model (see Wolfe 1994, for detailed discussion). Figure 1 illustrates some of the basic components of the model, adapted to the present stimuli.

The present study focused on activation in the feature maps proposed in various models. The Guided Search model is one that has been made fairly explicit, so we focus on it, but our data pertain to other models as well. We sought to determine the effect of presenting a partial form of the search stimulus (a display that activated one relevant feature map but not the other, and thus did not contain enough information to fully specify the target) before presenting the full display that the observer would search (see figure 2). The extent to which such a partial preview assists search should help to illuminate the mechanisms that guide visual selection, whatever model of search one chooses to adopt.

1.1 Priming

Priming is a change in the ability to process an object produced by prior exposure to that object (see eg Schacter and Badgaiyan 2001). In general, prior exposure to an object results in faster identification of that object the next time it is encountered. Thus, a stimulus should be found more quickly the second time that display is viewed; the prime does not even need to be identical to the target in order to assist priming (eg semantic priming).

Maljkovic and Nakayama (1994) presented displays for which observers had to respond to the shape of a colour singleton, where the colour of this singleton varied from trial to trial (a red item among green distractors, or vice versa). Maljkovic and Nakayama (1994) found that, when the colour of the singleton target was repeated on the next trial, search was facilitated—ie the shape of the target was identified faster (see also Hillstrom 2000; Maljkovic and Nakayama 1996).

In the present study, one aspect of a search display was previewed in order to measure whether this exposure assisted search. In the colour preview condition, for example, once the preview has been seen, the colour feature map has been primed and may have begun to stimulate locations in the overall activation map (see figure 1). At this point, when the actual search display appears, the orientation map still needs to build up activations in its representation; however, statistically, the response should
Figure 1. Illustration of the Guided Search model (Wolfe et al 1989, and Wolfe 1994), adapted to the present stimuli. The stimulus leads to activation in various feature maps; for present purposes these are divided into sub-maps corresponding to different categories of stimulus (e.g., black versus white in the colour map, horizontal versus vertical in the orientation map). Locations in the activation map are activated to the extent that the corresponding feature-map locations are activated.
be ready earlier than without priming, given that only one half of the relevant information (ie item orientations) is in question upon presentation of the actual search stimulus. That is, progressively presenting the different features should shorten the amount of time needed to process the full search display. See Spivey et al (2001) for another search experiment that progressively presents feature information needed for visual search.

Finally, in previous work (Olds et al 2000a, 2000b, 2001) evidence was found that a brief exposure to a pop-out display (target different from one type of distractors on the basis of just one simple feature) can guide various kinds of difficult search, when extra distractors are added to that initial pop-out display. The present experiment also aimed to assist difficult search by using feature information, but here the initial display did not contain an actual target (see figure 2).

1.2 Spatial cueing

Our preview display might also be performing spatial cueing. In an attempt to disentangle several potential sources of set-size effects in visual search, Palmer (1995) described a cueing paradigm. Observers were shown a cue display which distinguished between possible target locations in a subsequent search display, and locations that would not contain the target (half the cues were white and half were black). This display was followed by the search display. Palmer showed that the relevant set size (ie number of cued items) affected performance (measured as contrast increment threshold—the contrast increment necessary for 75% performance) in the same way that actual set size generally does. Cueing the observer to a limited subset of locations where the target might occur decreased the number of objects that had to be searched (below actual set size). This type of priming result should generalise to conjunction search, and to measures of RT as well as contrast increment threshold.

1.3 Predictions

We expected that certain features of the search items could be used as cues in visual search. Therefore, a preview of one feature of the search items (eg their colour; see figure 2) should allow the observer to select certain stimuli to consider (those with the correct colour), perhaps in a similar way to Palmer’s (1995) location cues. The preview display should activate the relevant feature map in the brain, with 1 s being enough time for such a representation to be formed. When the entire search display is then shown, this activation should likely persist, and search should be ‘guided’ towards those items with the correct colour, more quickly than without this preview, thus facilitating target detection.

2 Experiment 1

2.1 Method

2.1.1 Observers. Fifteen observers with normal or corrected-to-normal vision, including the two authors, completed the experiment. They were tested for normal colour vision prior to the experiment.

2.1.2 Apparatus. Search displays were presented on Macintosh G3 computers, which collected and recorded data with software written for the MATLAB programming language and Psychophysics Toolbox (Brainard 1997). Stimulus colours were specified with the use of a technique described by Olds et al (1999).

2.1.3 Stimuli and procedure. Observers were tested individually in a darkened room. Each trial began with a 400 ms fixation symbol; then a 400 ms blank screen was followed by a search set consisting of 8, 16, or 24 items. These search items were pink horizontal distractors and yellow vertical distractors, and on 50% of trials the yellow horizontal target. In the control condition this search display was presented until the observer responded. In the colour preview condition (see figure 2), prior to presentation
of the search display, coloured square blocks were displayed in place of the search items for 1 s. The colours and locations of the squares corresponded directly to the colours and locations of the items to be presented in the search set immediately afterwards. That is, after 1 s each square preview item `lost sides' to become an oriented line of the same colour; it was this display to which the observer responded. In the orientation preview condition, before the search set was presented, 2-pixel-thick orange outlines of the search items were displayed for 1 s. The locations and orientations of the outlines corresponded directly to the locations and orientations of the items to be presented in the search set immediately afterwards. The orange colour of the outlines was intermediate between the yellow and pink colours of the search items in CIELuv space (in which distances between

Figure 2. Illustration of the sequence of displays in a trial, for the three conditions of experiment 1 (control condition, colour preview condition, orientation preview condition). Note that the actual search items were pink horizontal distractors, yellow vertical distractors, and a yellow horizontal target on half the trials; the background was gray (equiluminant with the equiluminant search items). In the orientation preview condition, the preview shapes were orange (see text for more description). The sizes of the items and spacing between them is not exactly replicated in this figure. A colour version can be viewed on the Perception website at http://www.perceptionweb.com/misc/p5162/.
colours correspond roughly to perceptual differences). After 1 s, the items filled in and changed to the colours of the search items (yellow and pink); it was this second display to which the observer responded.\(^{(1)}\)

The colours of the search items, preview items, and gray background were all equiluminant \((20 \text{ cd m}^{-2})\). At the observers’ viewing distance (approximately 60 cm), the stimulus lines subtended approximately 0.5 deg \(\times 0.3\) deg. The search items appeared in a virtual \(6 \times 6\) grid of potential locations; within this grid the position of each item was randomly perturbed up to 0.1 deg visual angle both horizontally and vertically. The entire \(6 \times 6\) array of potential item locations subtended approximately 7 deg visual angle. The target could appear in any of these locations except for the four corner locations.

The three conditions were presented blocked in each session; the order of the three conditions was counterbalanced across observers. Each of the three sessions consisted of one block of trials for each of the three experimental conditions; each of these blocks consisted of 192 experimental trials preceded by 10 practice trials. Each observer completed a total of 1728 experimental trials.

Observers were requested to press a key indicating the presence or absence of the target, as quickly as possible given a goal accuracy level of at least 90%. Having responded, on each trial observers received immediate feedback in the form of a ‘+’ (correct) or ‘−’ (incorrect) sign for 400 ms; this feedback acted as the fixation symbol for the following trial. Response time and accuracy were measured by the computer. At the end of each session, observers were shown their RT and error rates for each condition; observers were fully debriefed at the end of the study.

2.2 Results: reaction times

Outlier response times (RTs) more than 3 standard deviations from the mean of each condition were removed before analysis, along with trials where RT was less than or equal to 400 ms (anticipatory errors). This procedure resulted in the removal of 1.7% of trials overall across all observers.

Figure 3 displays the RT and error rates for target-present and target-absent trials, across the three conditions. Table 1 includes slopes for RT \(\times\) set size functions for the three conditions. Below are listed only the effects that reached significance.

2.2.1 Control versus colour preview. The correct RTs for the control condition and for the colour preview condition were entered into a within-subjects ANOVA with set size, present/absent, and condition as factors. Only the main effects of set size \((F_{2,28} = 78.270, p < 0.0001)\) and present/absent \((F_{1,14} = 58.372, p < 0.0001)\) reached significance. There was an interaction between set size and present/absent \((F_{2,28} = 75.239, p < 0.0001)\): set size affected RT more for target-absent trials than for target-present trials (for both control and colour preview trials taken together). Next, we focus on target-present trials, where the guidance might be expected to be especially important. The correct target-present RTs for the control condition and for the colour preview condition were entered into a within-subjects ANOVA with set size and condition as factors. There was a main effect of set size \((F_{2,28} = 58.348, p < 0.0001)\).

2.2.2 Control versus orientation preview. The correct RTs for the control condition and for the orientation preview condition were entered into a within-subjects ANOVA with

\(^{(1)}\)One of our previous pilot studies used gray outlines (darker than the gray background) for orientation preview shapes; this was seen to be distracting and so equiluminant primes were considered to be better for the orientation preview condition. Another pilot study used equiluminant filled orange bars (which then changed to pink or yellow filled bars, in the search display), the same shape as the subsequent search items; however, because the colour change was subtle and there was no change in shape between preview and search display, it appeared that observers were taking extra time to even notice that the preview items had changed to the search items (and thus search for the target could begin).
set size, present/absent, and condition as factors. There was a main effect of set size ($F_{2,28} = 98.536, p < 0.0001$) and present/absent ($F_{1,14} = 77.654, p < 0.0001$), but the main effect of condition did not reach significance (marginal, $p = 0.0677$). Across both target-present and target-absent trials, priming to orientation results in a marginally higher RT than the control; the results indicate that observers were somewhat slower at determining if the target was present or absent when orientation of the search set items was previewed than when it was not (see figure 3). There was an interaction between set size and present/absent ($F_{2,28} = 66.640, p < 0.0001$).

The correct target-present RTs for the control condition and for the orientation-preview condition were entered into a within-subjects ANOVA with set size and condition as factors. Only the main effect of set size ($F_{2,28} = 85.104, p < 0.0001$) reached significance.

Table 1. Slopes of the RT×set size functions for experiment 1.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Target-present</th>
<th>Target-absent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>17</td>
<td>50</td>
</tr>
<tr>
<td>Colour preview</td>
<td>21</td>
<td>54</td>
</tr>
<tr>
<td>Orientation preview</td>
<td>20</td>
<td>60</td>
</tr>
</tbody>
</table>

Figure 3. Experiment 1. Mean RT and percentage error data for target-present (left panels) and target-absent (right panels) trials. Data for the control (filled circles), colour preview (empty triangles), and orientation preview (empty circles) conditions are plotted separately. Error bars represent one standard error above, and one standard error below, the mean (across subjects) for each condition.
2.3 Results: error rates

2.3.1 Control versus colour preview. Error rates for the control condition and for the colour preview condition were entered into a within-subjects ANOVA with set size, present/absent, and condition as factors. There was a main effect of set size ($F_{2,28} = 3.5555, p < 0.05$) and present/absent ($F_{1,14} = 34.882, p < 0.0001$). While the interaction between condition and present/absent was not significant for RT results (see above), for error rates it was significant ($F_{1,14} = 5.2585, p < 0.05$): there was more of a difference between error rates for these two conditions for target-present trials than for target-absent trials (figure 3, bottom panels, show this clearly).

There was also a significant interaction between set size and present/absent ($F_{2,28} = 5.2094, p < 0.05$) for error rates. The interaction between set size and present/absent did exist for RTs, as mentioned above; but it went in a different direction. For RTs (figure 3, top panels), target-absent RTs increased more with set size than target-present RTs; this is commonly found. Error rates, however, increased with set size more for target-present trials than for target-absent trials (for all conditions; figure 3, bottom panels). This indicates a possible speed—accuracy tradeoff. However, given that none of the RT statistics involving condition was significant, none of our previous conclusions (or lack thereof) from these overall statistics is challenged. We turn instead to the target-present trial analyses. The target-present error rates for the control condition and for the colour preview condition, were entered into a within-subjects ANOVA with set size and condition as factors. There was a main effect of set size ($F_{2,28} = 4.5239, p < 0.05$). The main effect of condition was only marginally significant ($F_{1,14} = 4.2657, p > 0.05$). Figure 3 shows that the colour preview condition does seem to have lower overall errors than the control condition, especially at the two smaller set sizes. (Note that in speed—accuracy tradeoff terms, if errors were raised for those set sizes—and correspondingly RTs were decreased—that would actually result in a higher RT versus set size slope than is shown in figure 3. This would indicate less efficiency for colour preview search, albeit overall lower RTs.)

2.3.2 Control versus orientation preview. Error rates for the control condition and for the orientation preview condition were entered into a within-subjects ANOVA with set size, present/absent, and condition as factors. Only the main effects of set size ($F_{2,28} = 4.5876, p < 0.05$) and present/absent ($F_{1,14} = 62.175, p < 0.0001$) were significant. There was an interaction between set size and present/absent ($F_{2,28} = 9.3180, p < 0.001$): set size affected error rates more for target-present trials than for target-absent trials. Note that this is the opposite pattern from that found for the RT data (set size affected RT for target-absent trials more than for target-present trials). The error rates for target-present trials for the control condition and for the orientation preview condition were entered into a within-subjects ANOVA with set size and condition as factors. Only the main effect of set size ($F_{2,28} = 7.0817, p < 0.005$) was significant; this is consistent with the RT results.

2.4 Discussion

As expected, the larger the set size, the longer it took observers to determine if the target was present or absent. Response times were also slower on target-absent trials than on target-present trials.

The purpose of this study was to determine whether previewing one feature of the search items would assist conjunction search. The preview of one feature should have built up activation in the relevant feature map, and thus was expected to make observers faster and/or more efficient at finding the subsequent conjunction target.
2.4.1 Colour preview. Contrary to our expectations, the colour preview condition did not affect search speed (although the colour preview condition had marginally lower errors than the control condition for target-present trials). The results of experiment 1 indicate that, at least for the present displays and timing parameters, previewing colour does not provide particularly beneficial information.

The preview was predicted to help search either by activating the relevant feature map (colour or orientation), consistent with our interpretation of the Guided Search model, or in a more top–down manner as in spatial cueing (enhancing or suppressing locations based on match to target features, which might require more conscious involvement on the part of the observer). However, perhaps the sudden shape change of all items is enough to disrupt processing and eliminate any priming (despite the lack of accompanying luminance onset or offset), similar perhaps to change blindness (see eg O'Regan et al 1997).

2.4.2 Orientation preview. While there was no effect of colour preview, there was an effect of orientation preview. However, this effect was not in the expected direction. Observers actually performed worse than in the control condition when given a preview of item orientations. The preview shapes themselves might have affected the reaction times of the observers: perhaps the preview shapes were strange looking, and the observers were distracted by the odd shapes.

2.4.3 Item locations. In addition to exposing observers to the colours (or orientations) of the search items, the preview displays also exposed observers to the spatial locations of all the search items. That is, the preview indicated where all the search items would appear in the search display, which could be useful information because the full $6 \times 6$ grid was not filled on every trial (many locations were left blank for all set sizes). Thus one might expect the observers to perform even better, given that our previews actually indicated two features of the items in the subsequent search display. The work of Palmer (1995) on spatial cueing, mentioned above, also leads to such a prediction. Experiment 2 (below) pursues this issue further, spatially cueing only half the search items (including the target), which is more comparable to Palmer’s (1995) experiments than is this interpretation of the previews of experiment 1.

In both preview conditions, it is possible that the change that occurred when the preview transformed into the search display was distracting, and disrupted processing although the feature activation should have been helpful. However, it is not clear why this would have happened for our cueing experiments and not for other spatial cueing, or priming, experiments. Future work will test whether a blank screen in between the preview display and the search display facilitates search; however, the present study specifically sought to transform the preview shapes directly into the search shapes.

3 Experiment 2
A preview such as those used in experiment 1 could activate the relevant feature map and speed processing (bottom–up). On the other hand, in the colour preview condition for example, it could also be seen as indicating which search items will have the ‘right’ colour. It would then direct attention (in more top–down, or endogenous, fashion) to this subset of search items, as in spatial cueing. Spatial cueing may involve bottom–up attention attraction as well; however, unlike a colour preview display, simple spatial cues do not (directly) activate items’ colours in the colour map.

In experiment 2, we sought to investigate further the idea that spatial cueing could be involved in any assistance by a preview. This question was pursued although the evidence for any benefit of feature preview was somewhat weak in experiment 1 (and was nonexistent for orientation preview). In experiment 2, two spatial cueing conditions cued the locations of the horizontal lines (but not the locations of the vertical lines)
for 1 s before the search display; the yellow horizontal target, if present, always appeared in one of these cued locations (see figure 4).

3.1 Method

Experiment 2 was identical to experiment 1 with the following exceptions.

3.1.1 Observers. Fourteen observers (one of whom participated in experiment 1 previously—author EO) with normal or corrected-to-normal vision and normal colour vision participated.

3.1.2 Stimuli and procedure. In addition to the conditions presented in experiment 1, this experiment also included two spatial cueing conditions, in which the locations of the horizontal items were preceded for 1 s by small dots. These cue dots were black in the black spatial cue condition (4 pixels wide), and equiluminant orange (the same colour as used for the outline cues in the orientation preview condition) in the orange spatial cue condition (8 pixels wide). The two different spatial cueing conditions were included in order to compare luminance cues with equiluminant cues [see Lambert et al (2003); note though that their experiments involved a single cue rather than multiple cued objects as in Palmer (1995) and the present experiment].

The five conditions were presented blocked in counterbalanced order; each observer performed one session in which five blocks, of 96 trials each, were each preceded by 10 practice trials (for a total of 480 experimental trials per observer).

3.2 Results: reaction times

Data for four observers were not included because of high error rates in some conditions (mean overall error rates of 4%, 2%, 6%, and 14% for these four observers, but error rates of 20%, 25%, 25%, 70% in some conditions, respectively). Outlier RTs more than 3 standard deviations from the mean of each condition for each observer were removed before analysis, along with RTs less than or equal to 400 ms. This procedure resulted in the removal of 0.83% of trials overall. Figure 5 shows the RT and error data; and table 2 includes slopes for the RT versus set size functions for the different conditions.

Only significant effects are reported below. The main effects of set size (for overall analyses, and for analyses of target-present trials alone) and present/absent (for overall analyses) were significant for all RT analyses performed, so these statistics are not mentioned in each case as these factors are not the present focus.

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![Figure 4](http://www.perceptionweb.com/misc/p5162/)

**Figure 4.** Experiment 2, black spatial cue condition trial structure. Orange spatial cue condition trial structure was the same, except that the cue dots were orange and equiluminant with the background colour. A colour version of this figure can be viewed on the *Perception* website at [http://www.perceptionweb.com/misc/p5162/](http://www.perceptionweb.com/misc/p5162/).
3.2.1 Control versus colour preview. The correct RTs for the control condition and for the colour preview condition were entered into a within-subjects ANOVA with set size, present/absent, and condition as factors. In addition to significant main effects of set size and present/absent, the main effect of condition was significant ($F_{1,9} = 16.760, p < 0.005$): overall, RTs for the colour preview condition were shorter than those for the control condition. There was an interaction between condition and present/absent ($F_{1,9} = 7.1564, p < 0.05$): the control condition and the colour preview condition were more different for target-absent trials than for target-present trials. There was also an interaction between set size and present/absent ($F_{2,18} = 27.182, p < 0.0001$): set size affected RT more for target-absent trials than for target-present trials. For target-present trials taken alone, the main effect of condition approached, but did not reach, significance ($F_{1,9} = 4.2229, p = 0.07$). (Figure 4 shows that, indeed, the difference between these two conditions is much stronger for target-absent trials; see below.)
3.2.2 Control versus orientation preview. There was an interaction between set size and present/absent \( (F_{2,18} = 38.181, p < 0.0001) \). No effects involving condition were significant. For target-present trials taken alone, no effects involving condition were significant.

3.2.3 Control versus black spatial cues. Only an interaction between set size and present/absent \( (F_{2,18} = 28.372, p < 0.0001) \) was significant. For target-present trials taken alone, no effects involving condition were significant.

3.2.4 Control versus orange spatial cues. Only the interaction between set size and present/absent \( (F_{2,18} = 36.112, p < 0.0001) \) was significant. Just as in the case of black spatial cues, for orange spatial cues, for target-present trials taken alone, no effects involving condition were significant.

3.3 Results: error rates

Error rates were low, and they fell into a pattern different from the error rates of experiment 1. They are discussed below, and compared with RT results, only when analyses reach significance at the 0.05 level. In all of the overall analyses of error rates, the main effect of present/absent was significant (miss rates were higher than false alarm rates; see figure 5); the detailed statistics are not reported for each.

3.3.1 Control versus colour preview. There was an interaction between set size and present/absent \( (F_{2,18} = 8.7578, p < 0.005) \). Note that for this and the following three comparisons this is the opposite pattern from that found for the RT data (RT increased with set size for target-absent trials more than for target-present trials, whereas error increased with set size more for target-present trials). No effects involving condition were significant. For target-present trials taken alone, only the main effect of set size \( (F_{2,18} = 4.5616, p < 0.05) \) reached significance. Because both errors and RTs increased with set size, this finding does not indicate a speed–accuracy tradeoff.

3.3.2 Control versus orientation preview. Set size affected error rates more for target-present trials than for target-absent trials \( (F_{2,18} = 4.4899, p < 0.05) \). The three-way interaction of condition \(|\times| \) set size \(|\times| \) present/absent was significant \( (F_{2,18} = 4.1156, p < 0.05) \), which is difficult to interpret. For target-present trials taken alone, no effects reached significance.

3.3.3 Control versus black spatial cues. Set size affected error rates more for target-present trials than for target-absent trials \( (F_{2,18} = 5.8295, p < 0.05) \). The three-way interaction of condition \(|\times| \) set size \(|\times| \) present/absent was significant \( (F_{2,18} = 7.1538, p < 0.01) \). There is no such significant interaction for the RT data, and it is somewhat difficult to interpret this effect in the error data because the control target-present errors jump around a lot. That interaction is not crucial to the present questions about condition, so this speed–accuracy tradeoff is not a major concern. For target-present trials taken alone, errors increased with set size \( (F_{2,18} = 4.1707, p < 0.05) \). The interaction of condition \(|\times| \) set size was significant \( (F_{2,18} = 4.5338, p < 0.05) \); misses for the control condition and the black spatial cues condition varied differently with set size; however, figure 5 shows that it would be difficult to confidently interpret this interaction as clearly showing greater efficiency for search after black spatial cues than for search without any preview.

3.3.4 Control versus orange spatial cues. There was an interaction between set size and present/absent \( (F_{2,18} = 4.3333, p < 0.05) \). The three-way interaction of condition \(|\times| \) set size \(|\times| \) present/absent was significant \( (F_{2,18} = 4.2719, p < 0.05) \); see discussion above. For target-present trials taken alone, no effects were significant.

To conclude, the error results do not compromise the conclusions above reached on the basis of the RT data, the main conclusion about condition being that there were faster RTs for colour preview than for the control condition, uncompromised by speed–accuracy tradeoffs.
3.3.5 *Target-absent trials.* Although these comparisons were not planned, and thus are suggestive rather than conclusive, we analysed target-absent trials alone as well, because figure 5 indicated that response time differences between the conditions were larger on target-absent trials. For target-absent RTs, the main effect of set size was significant for all comparisons. Only for the control versus colour preview comparison was there any other significant effect—a main effect of condition ($F_{1,9} = 18.074, p < 0.005$): target-absent RTs were shorter in the colour preview condition than in the control condition. 

As regards target-absent errors, several analyses of the false alarm rates approached significance but none reached the 0.05 level. In particular, none involving condition even approached significance for the control versus colour preview comparison, which was the only significant target-absent RT effect. Thus the data from the target-absent trials suggest that search was faster with a colour preview than in the control condition (but there was no evidence that the orientation preview or spatial cues provided any assistance).

3.4 *Discussion*

3.4.1 *Colour preview.* The colour preview helped search, especially on target-absent trials. This facilitation was expected; one remaining question is why the facilitation was greater on target-absent trials than on target-present trials. Because target-present responses are almost always faster than target-absent responses, one could argue that when target-present performance is at ceiling only target-absent performance can be made faster. Another question is why experiment 1 failed to produce evidence that colour preview helps search. Figure 3 shows a bit of this effect for experiment 1, in the target-absent RTs and the target-present errors. One possible explanation might be if there were more noise in the data from experiment 1; however, observers performed 576 trials per condition in experiment 1 (96 observations per cell), and only 96 trials per condition in experiment 2 (16 observations per cell), so in fact one might have expected more power in experiment 1. Only one observer performed experiment 2 after experiment 1, so practice is not a likely overall explanation.

3.4.2 *Orientation preview.* As in experiment 1, in experiment 2 the orientation preview did not assist search. Whether this consistent lack of assistance is caused by a difference in orientation versus colour in guiding attention in general, or a difference in the salience of the two dimensions in the present particular stimuli, cannot be determined by the present data. It is possible that the equiluminant outlines were somewhat subtle, and, given that luminance information is needed for good detailed shape discrimination, it is possible that this subtlety could have hindered observers. However, performance on the shape/colour conjunction search task was generally good, so equiluminance clearly did not prevent shape discrimination (for the filled shapes of the search stimuli; and the preview outline shapes were definitely visible).

3.4.3 *Spatial cueing.* Neither black spatial cues nor equiluminant orange spatial cues assisted search. If luminance spatial cues are *not better* than (roughly) equiluminant spatial cues, this is surprising—Lambert et al (2003), whose stimuli were much more carefully equated for subjective luminance than the present stimuli, found overall much better guidance of attention by luminance cues than by equiluminant cues. It could be argued that it is confusing for observers if a luminance cue is followed by an equiluminant display, in part because luminance is not relevant for the search task (see eg Folk et al 1993), and in part because activation of the stronger luminance pathway right before search of an equiluminant display could weaken the processing power of the pathway capable of processing the equiluminant display (this, however, is just speculative).
Note that Palmer (1995) inserted a blank screen between the spatial cues and the search item display (i.e., 250 ms cue display, 750 ms blank screen, then search display). The present experiment did not include a blank screen, so as to keep the temporal characteristics for the cueing conditions the same as those for the other preview conditions. In the colour and orientation preview conditions, it was important to have the preview items ‘turn into’ the search items, maintaining spatiotemporal continuity (to give the preview the best chance of helping search).

4 Experiment 3
In addition to investigating further whether the colour and orientation preview displays could help processing of the search display, in experiment 3 both preview displays were presented sequentially before the target: either colour – orientation preview, or orientation – colour preview (see figure 6). The goal was to determine whether any assistance afforded by the two feature previews could combine. One possibility would be that assistance could combine roughly additively. On the other hand, the combined assistance could be less than the assistance afforded by one preview only, for example if the orientation preview eliminated the somewhat weak assistance of the colour preview. Finally, the combined assistance could be greater than the assistance afforded by the two previews individually. This is because the two previews together specify all the information needed for a search response—the colours and orientations of all the search items. Experiment 3 was a test of observers’ ability to integrate across the two preview displays. Both orderings of the previews were used in order to determine whether it was most helpful to see one kind of single feature information before the other. Thus this

![Colour then orientation preview condition](image)

![Orientation then colour preview condition](image)

**Figure 6.** Experiment 3. Colour–orientation preview condition, and orientation–colour preview condition, trial structure. A colour version of this figure can be viewed on the Perception website at [http://www.perceptionweb.com/misc/p5162/](http://www.perceptionweb.com/misc/p5162/).
experiment was a test of the extent to which the proposed feature maps depend on one another, in order to explore further the guidance of attention.

4.1 **Method**

Experiment 3 was identical to experiment 1 with the following exceptions.

4.1.1 **Observers.** Five observers with normal or corrected-to-normal vision and normal colour vision participated. One observer, author EO, had participated in both experiment 1 and experiment 2 previously; three others had previously participated in experiment 2 only; the fifth observer had not participated in either experiment 1 or experiment 2 previously.

4.1.2 **Stimuli and procedure.** In addition to the conditions presented in experiment 1, in experiment 3 two double-preview conditions were also presented: *colour – orientation preview*, and *orientation – colour preview* (see figure 6).

Experiment 3 required variety in the proportions of the two distractor types so that no individual preview display alone could indicate the correct response. That is, in figure 2, for the colour preview condition, note that for set size 8 there are equal numbers of squares of the two colours—the search display on the right shows that the yellow horizontal target has replaced a *yellow* distractor (so that there are four pink distractors and three yellow distractors). Otherwise, if the target could replace a *pink* distractor, then the preview display would have five yellow and three pink items and thus the single preview display would indicate that the target was present. (2)

In the orientation preview condition, likewise, the target must replace a horizontal distractor, otherwise the proportion of horizontal and vertical shapes in the preview display would indicate whether the target was present or not (this proportion is fairly obvious for small set sizes, especially given that the preview display is shown for 1 s). Note that in one preview condition the target must replace a yellow vertical distractor, and in the other preview condition the target must replace a horizontal pink distractor. Because in experiment 3 both previews were presented in a single trial, the observer would be able to perform the task on the basis of (counting items in) just one preview display, if the method previously used for creating stimuli in the pure colour preview condition, or for the pure orientation preview condition, were used. Therefore, rather than having an equal number of each type of distractor and then the target replacing a particular distractor type on target-present trials, for all conditions of experiment 3 the target could replace *either* distractor type, and in addition on a randomly selected half of the trials one distractor was switched from one type to the other type (one of the distractor types was chosen randomly to get an extra item, and the other type then got one fewer item). Thus for set size 8, if the target was present, then the display could have 4 and 3 yellow vertical and pink horizontal distractors, respectively; or 3 and 4, or 5 and 2 or 2 and 5. If the target was absent the display could have 4 and 4, 3 and 5, or 5 and 3 yellow vertical and pink horizontal items. This way the proportion of colours or orientations in the individual preview displays did not indicate target presence or absence. (It is possible that, if the observer noticed only 2 of a particular orientation or colour in one of the preview displays, he or she could figure out that the target was present, but as observers were not informed of any details about distractor proportions we believe that to be highly unlikely; the one author who was an observer for the experiment did not consciously use this as a strategy).

(2) It would be conceivable that observers could then determine, in the actual search display, whether there were an uneven number of horizontal versus vertical lines—more horizontal lines would indicate target presence given that the target must replace a vertical distractor. This could be true for many of the search tasks in the literature and it is not a major concern for the present experiments.
The five conditions were presented blocked in a partially counterbalanced order. Each observer performed four sessions in which five blocks of 96 trials each were each preceded by 10 practice trials (for a total of 1920 experimental trials per observer).(3)

4.2 Results: reaction times
Outlier RTs more than 3 standard deviations from the mean of each condition were removed before analysis. Short RTs were not removed in addition to the outliers, because it was possible in the double-preview conditions that full information was available even before the search display itself was shown (and thus an RT of 200 ms could in fact reflect valid confidence in the search response). However, responses were not allowed by the computer during the preview displays. The outlier screening procedure resulted in the removal of 1.2% of trials overall. Figure 7 shows the RT and error data; and table 3 includes slopes for the RT versus set size functions for the different conditions.

Table 3. Slopes of the RT × set size functions for experiment 3.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Target-present</th>
<th>Target-absent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>15</td>
<td>52</td>
</tr>
<tr>
<td>Colour–orientation preview</td>
<td>32</td>
<td>78</td>
</tr>
<tr>
<td>Orientation–colour preview</td>
<td>23</td>
<td>58</td>
</tr>
<tr>
<td>Colour preview</td>
<td>19</td>
<td>58</td>
</tr>
<tr>
<td>Orientation preview</td>
<td>15</td>
<td>57</td>
</tr>
</tbody>
</table>

Below only significant effects are reported. The main effects of set size (for overall analyses and for target-present trials alone) and present/absent (for overall analyses only), and the interaction of set size and present/absent, were significant for all RT analyses done (unless otherwise noted), so these statistics are not mentioned in each case as these factors are not the present focus.

4.2.1 Control versus colour preview. The correct RTs for the control condition and for the colour preview condition were entered into a within-subjects ANOVA with set size, present/absent, and condition as factors. No effects were significant beyond the main effects of set size and of present/absent, and the interaction of set size and present/absent. For target-present trials taken alone, no effects involving condition were significant.

4.2.2 Control versus orientation preview. The main effect of condition was significant ($F_{1,4} = 36.611, p < 0.005$): the orientation preview slowed search down. The interaction of condition and present/absent was significant ($F_{1,4} = 10.524, p < 0.05$): this slowing

(3) While JG was completing his second experimental session, technical complications caused the session to be stopped at approximately the 265th trial (about halfway through the third condition, which was the orientation–colour preview condition). As a result it was required that a new data matrix be constructed, and this would have led to slight imperfections in the counterbalancing of the target positions. For this experiment, the MATLAB program divides the set of 32 possible target positions (all positions in the $6 \times 6$ matrix except the four corners) into two groups of 16, and creates one trials file from each subgroup of positions (so, in the first session only a randomly selected half of possible target locations would be used, and in the second session the other half would be used), randomising things like set size and present/absent within each file. This results in experimental sessions of reasonable length, and a pair of sessions will test every target position equally. If there is a problem with a file in between the first and second sessions, this target–position counterbalancing scheme is disrupted. We do not believe this to be a problem for observer JG's data. In addition, because of these approximately 65 trials being discarded, observer JG did complete a full set of trials in this condition in order to complete the session, which resulted in extra practice for JG for this type of trial. We do not believe this to be a major concern.
The main effect of condition was significant ($F_{1,4} = 10.688$, $p < 0.05$), with this double-preview condition producing faster RTs than the control condition. The interaction between condition and set size was also significant ($F_{2,8} = 52.377$, $p < 0.0001$), indicating that set size affected this double-preview condition more than the control condition (figure 7 shows that the RT versus set size slope is steeper for the colour–orientation preview condition than for the control condition). For target-present trials taken alone, the effect of condition was significant ($F_{1,4} = 15.137$, $p < 0.05$) as was the interaction of condition × set size ($F_{2,8} = 27.947$, $p < 0.0005$): double-preview search was faster and less efficient than control search.

4.2.4 Control versus orientation–colour preview. The interaction between condition and set size was significant ($F_{3,8} = 27.220$, $p < 0.0005$), indicating a greater effect of set size on orientation–colour preview search than on control search (as for the colour–orientation preview condition, above). However, the main effect of condition was not significant, so the colour–orientation preview condition produced search that was less efficient but not (reliably) faster than search without a preview. For target-present trials taken alone, the interaction of condition and set size was significant ($F_{2,8} = 9.5814$, $p < 0.01$), again indicating less efficient search after the orientation–colour preview than without any preview.
4.2.5 Colour–orientation preview versus orientation–colour preview. The main effect of condition was significant ($F_{14} = 13.921, p < 0.05$), as was the interaction of condition $\times$ set size ($F_{28} = 29.688, p < 0.0005$): colour–orientation preview search was faster than orientation–colour preview search but less efficient. The three-way interaction of condition $\times$ set size $\times$ present/absent was also significant ($F_{28} = 4.5366, p < 0.05$). Figure 7 shows that the slope difference between the two conditions is greater for target-absent trials than for target-present trials. For target-present trials taken alone, the main effect of condition was significant ($F_{14} = 14.530, p < 0.05$), as was the interaction of condition $\times$ set size ($F_{2,8} = 5.9733, p < 0.05$).

4.3 Results: error rates
Error rates were low, and will be mentioned only when analyses reach significance at the 0.05 level. In all of the overall analyses of error rates, except for the analyses of the two double-preview conditions together, the main effect of present/absent was significant (miss rates were higher than false alarm rates; see figure 7). No other effects reached significance except for the interaction of condition $\times$ present/absent ($F_{21,8} = 10.0, p < 0.05$) for the analysis of the control and orientation preview conditions. To conclude, the error results do not compromise the conclusions reached on the basis of the RT data.

4.4 Discussion
There is some complication with interpreting the slopes of the colour–orientation double-preview condition: it appears that search became faster (mean RT) but less efficient (see figure 7 and table 3 for the RT versus set size slopes) with this double preview. However, perhaps the preview was simply most helpful at smaller set sizes, owing to observers’ limited capacity for retaining item information. It has been proposed that only a small number of items (eg 4) can be encoded (see Duncan and Humphreys 1989; Pylyshyn 2000) for certain tasks. For example, Pylyshyn has found that only 4 items can be tagged for tracking in a moving-item display. With a larger number of relevant items, only a subset can be tagged. Such a capacity limit could explain why facilitation was much greater for small set sizes than for large set sizes in experiment 3. Therefore, we can interpret the present results as showing an impressive facilitation of performance at small set sizes, or as showing a surprising lack of facilitation at larger set sizes. This lack of facilitation is surprising given that all of the information required for response is present in the pair of previews (this lack of facilitation is more impressive for even the smaller set sizes with the orientation–colour double-preview). Therefore this type of task could be a new way of measuring a particular kind of cognitive capacity limit.

The orientation–colour double-preview condition, on the other hand, had a steeper RT versus set size slope than the control condition but was not significantly faster overall. This asymmetry in facilitation, where colour–orientation previewing was more helpful than orientation–colour previewing, merits further study. One possible explanation is that perhaps the colour preview display indicated colour in a better way than the orientation preview display indicated orientation, and this difference made the colour preview display facilitate grouping (of relevant items, ie the yellow squares and their locations) more. Thus in the colour–orientation preview condition, observers are given information that allows easy grouping, and they are then able to retain that information even when the coloured squares turn into outline rectangles, for long enough to more serially search through the relevant items (the items they remember to be relevant based on their colour) to find an outline shape with the correct orientation (horizontal). Perhaps the orientation preview provides information that is more difficult to retain, when the orientation preview display is replaced by the colour preview display, in the orientation–colour preview condition, and that is why this condition
facilitates search less than when the previews are presented in the reverse order. Further research could determine whether it is orientation in general that affords grouping less well than colour, or our particular orientation preview shapes.

Clearly (and in response to the discussion following experiment 2), the orientation outlines were not too subtle, because assistance by orientation plus colour was much greater than assistance by colour alone. Therefore the orientation cues must contain useful information that the observer is able to use in some situations. Put another way: the orientation preview hurts performance (experiments 1 and 3), but when it is presented with the colour preview it helps (especially if the colour preview appears first). This is clearly in part because the two previews together fully specify the information required for response. However, performance does not reach ceiling for all set sizes, and the specific nature of the facilitation afforded when both previews are presented is a question for further research.

5 General discussion
The present experiments have demonstrated search facilitation by a colour preview, and even greater facilitation if that preview is followed by an orientation preview. Although the orientation preview was useful if presented after the colour preview, it was not useful (it was even hurtful) if presented alone before the search display. Previewing colour and then orientation before the search display was more helpful than previewing orientation and then colour. These results have implications for issues such as the capacity of the visual system to retain feature information about display items, and the integration of information about different features.

5.1 Different difficulties of feature dimensions in the present stimuli
Should shape or colour be expected to ‘guide’ search better in a conjunction task (and could this answer be relevant to the present lack of facilitation by the orientation preview display)? This answer will likely depend on the particular stimuli; the easier of the two relevant feature discriminations may be used to guide search (ie rule out one subset of the items as irrelevant, for example all vertical items, in order to mainly consider the remainder as more relevant, for example all horizontal items). Thus, if the colours are fairly similar—pinkish-orange and yellowish-orange—and the shapes are very different—long thin horizontal and vertical bars—then perhaps only shape priming will enhance this segregation and thus should be expected to help search. Sobel and Cave (2002) have manipulated the discriminability of features in conjunction search, along with the ratio of the two distractor types. They found that, when stimulus features along one dimension were particularly discriminable, observers tended to search the smaller group of items (eg 3 red items rather than 5 green items, if colour was the more discriminable feature). They also found that, when one conjunction feature was much more discriminable than the other, observers could guide search by that feature on the basis of instructions (eg follow verbal instructions to consider only red items, when colour was the more discriminable feature). The smaller-group search of a regular conjunction search display (as used by Sobel and Cave 2002) could be different from priming a conjunction search display by partial feature information (as in the present experiments). It could be argued that priming the more difficult dimension should actually provide more assistance if discriminability of the other feature was closer to ceiling—this is an empirical question.

The present stimuli were not created with such a discriminability discrepancy in mind. To show that it is discrimination difficulty that affects guidance and not something about the particular feature dimensions, further research can present a conjunction task involving a particularly easy colour discrimination (perhaps even including a luminance difference between the two colours) and a particularly difficult shape discrimination
(eg short rectangles, with similar horizontal and vertical lengths), and then reverse these difficulties, as in Sobel and Cave (2002). Our laboratory has not yet pursued that line of inquiry. It is possible that, although the two feature dimensions were perhaps fairly equivalent in the present search stimuli, the preview displays may not have indicated their respective features equally well. That is, colour seems to have been well shown by the colour preview display (ie there was some evidence of facilitation by the colour preview), but perhaps the equiluminant outline rectangles did not indicate orientation in as simple a manner (see footnote 1). However, this explanation does not clarify why neither spatial cue was useful.

5.2 Other types of preview

Presenting partial feature information for every search item is not the only kind of potentially useful preview. In ‘visual marking’ experiments (Watson and Humphreys 1997), a set of distractors is previewed, and then, after a delay, more distractors are added (along with the target on half the trials; these are the ‘new’ items). Observers can ignore the previewed distractors in subsequent difficult search—that is, the RT versus set size slopes resemble those for displays lacking the extra initial distractors (ie displays containing the set of ‘new’ items only). Watson and Humphreys (1997) showed that 400 ms is a sufficient duration for the preview, in order to obtain such attentional de-prioritisation. Researchers have consistently found that previewing of distractors can help search of a subsequent display; for example Theeuwes et al (1998) showed that marking can occur for up to 15 previewed items.

Note that visual marking is a different kind of preview from that in the present experiments, and would be necessarily have identical effects. Visual marking experiments preview half the (intact) items (ie all of the features of half of the items), rather than half of the features of all of the items (as in the present colour and orientation preview conditions). That is, any item seen in the first portion of a visual marking display is a distractor and this is directly visible. In the present preview displays, on the other hand, this information could be figured out but is not immediately obvious: in the colour preview condition, pink squares will become pink horizontal distractors, but they are not identical to distractor items yet. It is possible that the pink squares in the colour preview display could be marked for search of the subsequent display, unless the change in shape disrupted marking; however, it is not clear that marking would occur if these intermediate (cognitive) steps were necessary [as opposed to when a distractor appears intact, as in Watson and Humphreys (1997)]. Watson and Humphreys (2000) showed evidence for top—down control of marking, but they did not test the present kind of preview stimulus. The inhibition involved in visual marking would be a different kind of benefit from the expected excitatory activation of feature maps described in section 1.3 above.

It is interesting that the present single-preview conditions helped search less than the distractor preview displays in the visual marking experiments of Watson and Humphreys (1997) and others. One particular experiment is similar to the current preview displays in one respect. In their experiment 4a, Watson and Humphreys (1997) presented partial green H distractors (two of five defining segments were illuminated), followed by the appearance of blue T distractors (and a blue H target on half the trials). When the second set of items was added, the remaining segments of the partial blue H distractors were added as well, forming whole letter H distractors. Thus, initial items changed shape when the preview display turned into the search display (as in the present experiments). Watson and Humphreys found that observers were unable to exclude the old distractors from search when these items underwent this luminance change (letter segments were a different luminance from the background). However, note that there are several important differences between Watson and Humphreys’s marking experiment and the
present preview displays. Watson and Humphreys's (1997) stimuli underwent both a shape change and a luminance change, and these changes together disrupted marking. The present preview and search items were equiluminant with their backgrounds, and, when they underwent a shape change, they did not undergo a luminance change [see Donk and Theeuwes (2001) and Kunar et al (2003) for discussions whether marking requires a luminance onset in the new items]. Thus for the important question whether a shape change without a luminance change would be disruptive to the priming effects that were expected with the present preview displays, Watson and Humphreys's (1997) partial-H preview experiment only gets at half this question.

One might ask whether the present stimuli allow any comparison with marking. Olds and McMurtry (2003) have shown that visual marking occurs for stimuli similar to those used in the present experiments (oriented lines of similar colours to the present stimuli), in an experiment designed to test marking with displacement of visual stimuli. The main difference was that the background used by Olds and McMurtry (2003) was darker than the search items (thus appearance or disappearance caused a luminance change), whereas in the present experiment the search items were equiluminant to the background. Regarding the luminance difference between background and search items, Donk and Theeuwes (2001) have argued that luminance changes are necessary for marking to occur, while Kunar et al (2003) have argued the opposite. Thus the question whether visual marking could occur with the present equiluminant stimuli could be a subject for further study.

5.3 The Guided Search model

It is not clear how to interpret all of the present results in the context of our interpretation of Guided Search (Wolfe 1994; Wolfe et al 1989). The results of the colour preview condition provide some support for our characterisation of priming of feature maps. The results of the orientation preview condition, on the other hand, tentatively suggest that some previewing may actually interfere with the functioning of search—interfering also, perhaps, with the guidance of serial search by feature maps that is proposed by Guided Search. Finally, the results of the colour–orientation preview condition in experiment 3 indicate that these priming effects can combine superadditively (and with an asymmetry) in ways that should be explored further. For example, a model such as Guided Search could be presented with feature information structured as in figure 6 (first colour feature information only, then orientation feature information only, then a full search display), and the model's performance could be compared with that of human observers.

Differences in effectiveness between different kinds of preview are important because they illuminate the cognitive and perceptual mechanisms at work when targets must be found in complex visual displays. Remaining mysteries, raised by the present experiments, are: why was facilitation by the colour preview greater on target-absent trials than on target-present trials in experiment 2; why did luminance spatial cues not help any more than equiluminant spatial cues in experiment 2; why does an orientation preview hinder performance when presented alone but facilitate performance when presented after a colour preview; and why was the colour–orientation double-preview condition more helpful than the orientation–colour double-preview condition. Understanding of these basic mechanisms can be applied to improving the design of any piece of equipment which requires a human user to notice or find something (eg design of car dashboards to increase safety; design of radar screens to decrease lapses in target detection).

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References


Maljkovic V, Nakayama K, 1994 “Priming of pop-out: I. Role of features” Memory & Cognition 22 657 – 672
Palmer J, 1995 “Attention in visual search: Distinguishing four causes of a set-size effect” Current Directions in Psychological Science 4 118 – 123

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