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Dissociating the effects of similarity, salience, and top-down processes in search for linearly separable size targets

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In two experiments, we explored the role of foreknowledge on visual search for targets defined along the size continuum. Targets were of large, medium, or small size and of high or low similarity relative to the distractors. In Experiment 1, we compared search for known and unknown singleton feature targets as a function of their size and similarity to the distractors. When distractor similarity was high, target foreknowledge benefited targets at the end of the size continuum (i.e., large and small) relatively more than targets of medium size. In Experiment 2, participants were given foreknowledge of what the target was not. The beneficial effect of foreknowledge for endpoint targets was reduced. The data indicate the role of top-down templates in search, which can be "tuned" more effectively for targets at the ends of feature dimensions.

Models of visual search generally distinguish between top-down and bottom-up processes (e.g., Duncan & Humphreys, 1989; Treisman & Sato, 1990; Wolfe, 1994). Bottom-up processes are generally held to function by computing difference signals for input signals from items in the visual field, on the basis of their physical similarity (e.g., Bravo & Nakayama, 1992; Wolfe, 1998). This contrasts with top-down processes, which modulate input processes via a representation of the target. One way this may happen is that a representation of the target (e.g., foreknowledge of its color) biases processing resources toward items in the visual field sharing the representation's properties (Chelazzi, Miller, Duncan, & Desimone, 1993; Duncan & Humphreys, 1989).

Hodsoll and Humphreys (2001) produced evidence for differential effects of target foreknowledge in relation to "linear separability" effects found for size-defined stimuli. A target is linearly separable from distractors if a straight line can be drawn through a feature space separating the target and distractor feature values (see Figure 1A). Stimuli are nonlinearly separable if the target falls on the straight line drawn between the feature values for the distractors (Figure 1B). D'Zmura (1991) and Bauer, Jolicœur, and Cowan (1996a, 1996b, 1998) characterized the effects of linear separability on search for targets defined along the color dimension. Search functions were fast and parallel for linearly separable targets and distractors. In contrast, if the target and the distractors were nonlinearly separable, search was more difficult and search functions were serial in nature. Similar effects in the size domain have been reported by Wolfe and Bose (1991) and Macquistan (1994). To investigate the effects of target foreknowledge under conditions of nonlinear separability, Hodsoll and Humphreys (2001) compared search for size targets when the target identity was known with those when the target was unknown and defined by being the singleton in the display (the only item with that particular feature value). If the standard search advantage for linearly separable targets was largely due to limitations on bottom-up computations (D'Zmura, 1991), there should be little effect of target foreknowledge on the linearly separable search conditions relative to on the nonlinearly separable search conditions (i.e., on search for large and small targets vs. search for medium targets). The data refuted this prediction. Target foreknowledge had the biggest effect on the linearly separable targets. Hodsoll and Humphreys (2001) proposed that when the target is known and linearly separable from the distractors, a template or linear operator can be easily "tuned" to the target's endpoint value along the feature dimension. This selectively benefits search in such a way that there is little effect of foreknowledge on targets that are nonlinearly separable from distractors.

Given that top-down processes seem to be important in search for linearly separable targets, we first ask here how their influence is modulated by the similarity relations between the targets and the distractors. Search is more difficult as target–distractor similarity increases (Duncan & Humphreys, 1989), and this suggests a need for greater top-down guidance under high target–distractor similarity conditions. However, as Hodsoll and Humphreys (2001) showed, the need for guidance in more difficult search conditions can be constrained by the effectiveness of the

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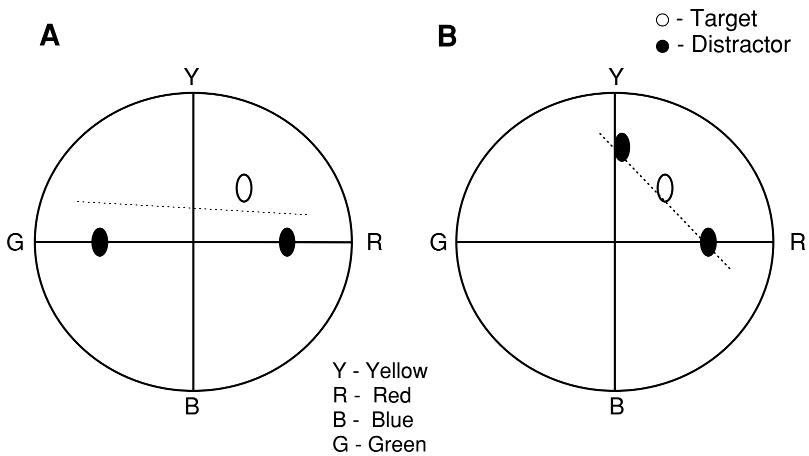

Figure 1. Two possible target–distractor configurations within a hypothetical color space. In Configuration A, the target is linearly separable from the distractors, as shown by the dashed line. In Configuration B, the target is not linearly separable.

guidance processes themselves. In their study, top-down knowledge was more beneficial for easier search tasks (with large or small targets), since only in these conditions could an effective top-down template or operator be set. In the present study, we examined the generality of this result by assessing whether target–distractor similarity and relative differences in salience constrain the effects of foreknowledge on search in a similar way to linear separability. To do this, we used stimuli in which the target and the distractors were always linearly separable along the size dimension. With these stimuli, we contrasted search for known and unknown (singleton-defined) targets that were either similar or dissimilar to the distractors.

There were three different sizes of stimuli—small, medium, and large—giving three possible targets, each of which could have two possible distractors. A small target could appear with medium or large distractors, a medium target with small or large distractors, and a large target with small or medium distractors. In the low-similarity condition, the large and small stimuli were paired together (large target and small distractors, or vice versa). The high-similarity conditions all involved pairings with the medium stimuli (either the small or the large target with medium distractors, or the medium target with small or large distractors). The effect of target foreknowledge was manipulated by blocking the target across a set of trials or by having identity vary randomly across trials (with the target defined by being the only item in the display with its particular feature value).

The pairing of each target with just one other type of distractor meant that, with our size-defined stimuli, the medium target was not nonlinearly separable relative to the distractors present. Nevertheless, this meant that, in terms of the feature values across the displays, the medium target was nonlinearly separable, relative to the other possible targets (large and small). Hodsoll and Humphreys (2001) suggested that participants might find it difficult to "tune" a template to a known target that is nonlinearly separable, since a midpoint value is liable to be less precisely defined relative to a value at the end. It is instructive to consider how relative size effects may affect memory templates on these search displays. The medium target with small distractors may be coded as larger than the distractors, whereas the same item may be coded as smaller when the distractors are large. This differential coding may affect the template applied to detect the target irrespective of any bottom-up differences in the perceptual signal given by the relative size contrast between the stimuli. For example, the template may shift across trials from *relatively large* to *relatively small*, slowing search. A redescription of this account in terms of setting a decision boundary is presented in the General Discussion section.

If it is easier to set a template for a target at the end of a feature dimension, this would lead to a differential impact in known search conditions. Importantly, participants may then find that top-down knowledge for the medium target here is not as effective for the small or large, even though medium targets are linearly separable within the display. This would demonstrate that top-down effects are not specific to the case of linear separability (e.g., due to the tuning of a linear operator that works for linearly separable items but not for nonlinearly separable items). Rather, such a finding would suggest that differential effects of target foreknowledge more generally reflect the tuning of a template to one end of a feature continuum.

In Experiment 2, we examined the effects of foreknowledge of what the target or the distractors were not. For example, the cue "not large" indicated that the target was either a small item among medium distractors or a medium item among small distractors. Although such a cue does not enable a specific template to be set for a target (cf. Duncan & Humphreys, 1989), it may enable a template to sample a restricted part of the feature space. This may then benefit performance in a similar way to known target search (effects larger on small and large targets, for which the template may be tuned more precisely), though the effects may generally be reduced (since the template will be less well specified).

In addition to examining effects of foreknowledge, we also evaluated carryover effects across trials. Previously, Hodsoll and Humphreys (2001) found no difference between the carryover effects for the different size targets. However, this might have been due to the nature of the present and absent tasks they used (although see Kristjansson, Wang, & Nakayama, 2002). Maljkovic and Nakayama (1994) argued that carryover effects are associated with the deployment of attention to a target item, which is not necessary when a target-present or target-absent judgment is made. Therefore, we used a compound search task, in which attention had to be moved to the target item to discriminate the compound target. We assessed whether this would now generate carryover effects that varied across the different size targets. If differential carryover effects could be found, this would have important implications. Rather than being purely bottom-up in nature, carryover effects too could be due to the tuning of a template, reinforced by the prior target on a trial. Thus, carryover effects may have a greater role to play for targets at the ends of feature dimensions, where it is possible to more easily set a template, than for targets defined along the midpoints of the dimension.

EXPERIMENT 1
Top-Down Knowledge for Linearly Separable Size Targets

Method

Participants. Sixteen participants (4 male and 12 female, mean age = 19.9 years) from the University of Birmingham took part in return for course credits: 13 were right-handed and 3 left-handed. All had normal or corrected-to-normal vision.

Apparatus. The experiment was programmed using MEL v2.01 running under Windows 95 DOS and run on a Pentium II/350-MHz computer with a Philips Brilliance 108MP monitor driven by an STB Velocity 128 graphics card.

Stimuli. The stimuli consisted of three circles of diameters of 0.61º, 0.84º, and 1.22º of visual angle (at distance of 0.75 m), classified as small, medium, and large, respectively. On a 640 × 480 VGA display, the individual stimuli subtended areas of 314, 616, and 1,257 pixels, the medium circle being twice the size of the small circle and the large circle being twice the size of the medium circle. Thus, the medium was midway between the small and the large circle in terms of area. The stimuli appeared light blue on a black background. The display was divided up into a 5 × 5 virtual grid subtending 8.15º of visual angle, each location being 50 pixels square. Within each array location, display elements were randomly offset from the center point by between 1 and 5 pixels. Target elements could appear in any of the 25 array positions, except for the outside corners and dead center. Distractors could appear in any of the 24 possible locations, apart from the dead center.

Design. There were five factors, all manipulated within participants.

Target foreknowledge. The target identity was either blocked or varied randomly on a trial-to-trial basis. In the latter condition, the target was a singleton among multiple distractors carrying the same feature values.

Target size. The target could be a small, medium, or large circle.

Distractor. There were two possible pairings of distractors for each target: for the small target, medium or large distractors [S(M) and S(L)]; for the medium target, small or large distractors [M(S) and M(L)]; and for the large target, small or medium distractors [L(S) and L(M)]. Figure 2 shows a large target with medium distractors.

Display size. Search displays consisted of 8 or 16 items.

Response condition. The participants responded as to whether a break in a small black annular within the target (0.1º of visual angle) was at the top or the bottom of the annular.

Procedure. The *known* and *unknown* conditions were presented over separate blocks of trials. In the known condition, the target and distractor identities were presented over a block of trials. The participants were informed of the identity of the target and distractor items (e.g., medium target with small distractors) at the beginning of each block. If the target was unknown, the participants were informed of this at the start of the block of trials, and they were instructed to look for the odd-one-out target. Each trial commenced with the appearance of a central fixation cross, the search display appearing 400 msec after the onset of the fixation cross. The participants were asked to look at the fixation cross at the beginning of each trial, but they were left free to make eye movements when the search items appeared. For all trials, the display remained visible until the participants responded or until 10,000 msec had passed. A new trial commenced after 750 msec if the previous trial was correct or after 1,000 msec if the response to the previous trial was incorrect. The participants were asked to respond as quickly and accurately as possible. Half of the participants responded "F" if the gap in the circle was at the top and "J" at the bottom; the other half pressed "J" and "F" for top and bottom, respectively. A short beep indicated when the participants made an error. For each target condition (target identity, distractor identity, display size, and known/unknown), there were 24 trials, giving a total of 576 trials.

Results

Visual search. For reaction times (RTs), we used a modified recursive outlier procedure with a moving criterion (see Van Selst & Jolicœur, 1994) that removed 173/8,857 data points (1.95%) of the correct RTs. The remaining correct RTs were entered into a four-way ANOVA with target knowledge, target size, distractor identity, and display size as factors. There were main effects of display size [$F(1,15) = 21.14$, $p < .001$], target identity [$F(2,30) = 89.67$, $p < .001$], distractor identity [$F(1,15) = 82.49$, $p < .001$], and target knowledge [$F(1,15) = 85.07$, $p < .001$]. RTs were longer at Display Size 16 relative to those

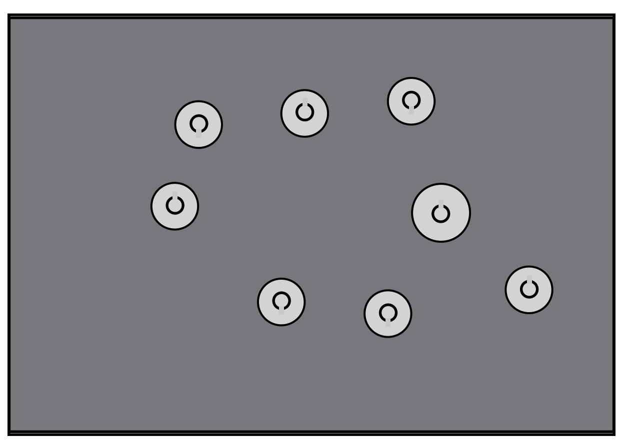

Figure 2. An example of a search display with the large circle as the target and medium distractors L(M).

at Display Size 8 and were fastest for the large target (791 msec), followed by the medium target (883 msec), and the small target (960 msec). Responses were almost 300 msec faster in the known condition (735 msec) than in the unknown condition (1,020 msec). Note that the distractor identity condition was only meaningful as an interaction term with target and is thus only reported so.

There was a two-way interaction between display size and target identity [$F(2,30) = 17.90$, $p < .001$]; the effect of display size was much greater for the small target than for the other target sizes. There was also an interaction between target and distractor identity [$F(2,30) = 172.13$, $p < .001$]. For the small target, RTs were much slower when it appeared with a medium distractor (1,140 msec) than when it appeared with a large distractor (784 msec). For the large target, RTs were slower when it appeared with a medium distractor (862 msec) than when it appeared with a small distractor (719 msec). For the medium target, there was little difference whether it appeared with a small or large distractor. The effect of target foreknowledge varied with target identity [$F(2,30) = 9.36$, $p < .002$]. The benefit of target knowledge was greatest for the small target (347 msec), followed by the large target (261 msec) and the medium target (244 msec). The interaction between target knowledge and display size failed to reach significance [$F(1,15) = 3.67$, $p = .075$].

There were three-way interactions of display size, distractor identity, and target identity. The effect of display size [$F(2,15) = 7.30$, $p < .005$] was much larger for the small target with medium distractors (15.5 msec/item)

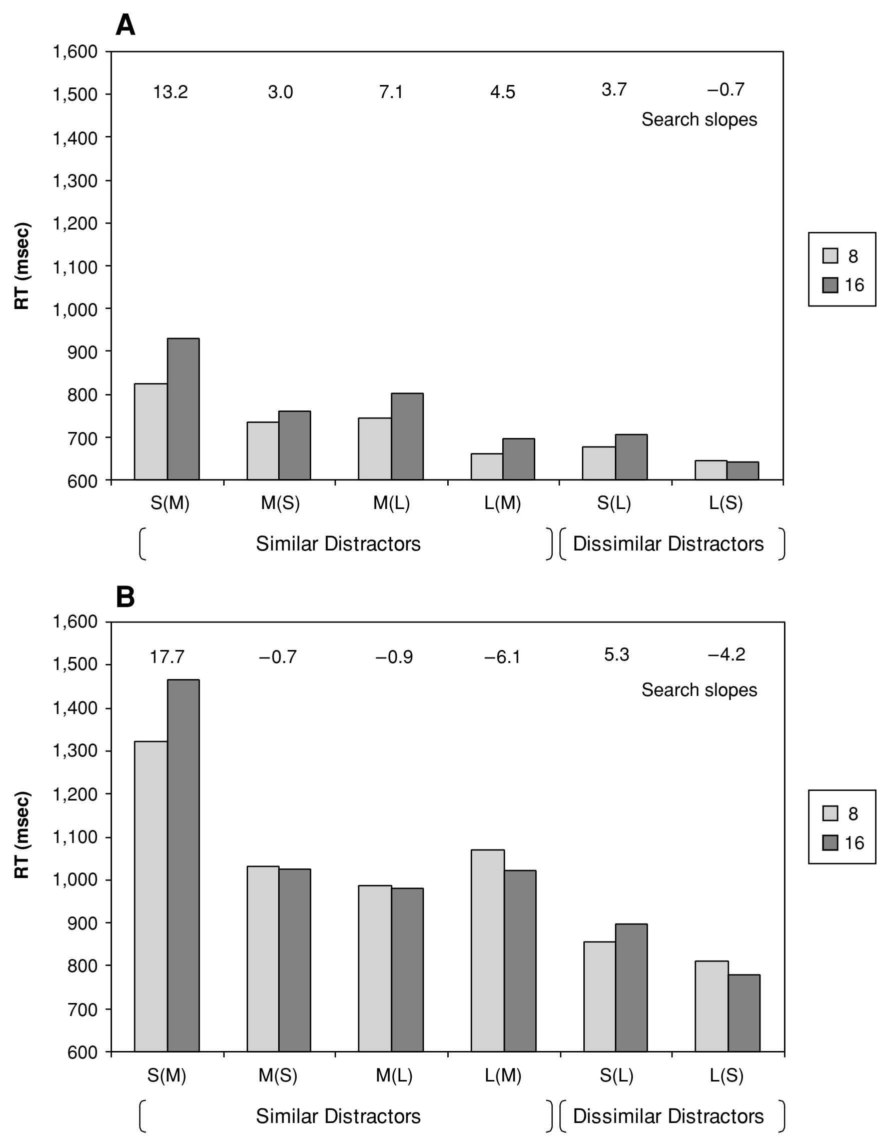

Figure 3. Mean correct RTs (in milliseconds) for the known search condition (A) and the unknown search condition (B) in Experiment 1 as a function of display condition (target size and distractor identity) and display size (8 or 16 items), including search slopes.

than for the rest of the target and distractor conditions (all less than 5 msec per item). There was also a three-way interaction between display size, target identity, and target knowledge [$F(2,30) = 3.50$, $p < .05$]. The lack of target knowledge led to a slight increase in search slopes for the small target relative to the known condition; however, for the medium and large targets, search slopes were relatively less in the unknown condition than in the known condition. The target identity, distractor identity, and target knowledge interaction was also significant [$F(2,30) = 74.01$, $p < .001$]. As can be seen from Figure 3, the cost of a lack of target knowledge for the small target was less when it appeared with large distractors than when it appeared with medium distractors. A two-way ANOVA for the small target RTs only with distractor identity and target knowledge as factors showed a significant interaction [$F(1,15) = 100.11$, $p < .001$]. Similarly, search for the large target in the known search condition was 34 msec slower when it appeared with medium distractors rather than small. In the unknown search condition, this difference reached 250 msec. Again, a two-way ANOVA on RTs to large targets showed a significant interaction between distractor identity and target foreknowledge [$F(1,15) = 78.44$, $p < .001$]. The interaction between target knowledge and distractor identity was reliable also for the medium target [$F(1,15) = 9.12$, $p < .004$]. The RT difference for the medium target appearing with the small distractors rather than the large switched from a 28-msec benefit in the known condition to a 45-msec cost in the unknown condition. The medium target showed some benefit of target knowledge, but the greatest benefit was for the small target (520 msec) and the large target (369 msec) appearing with medium distractors. The magnitudes of the effects of target foreknowledge are shown in Figure 4.

We found that errors were generally low (less than 8%) and followed the pattern of the RT data (see Table 1). A four-way ANOVA was conducted on mean errors with knowledge, target identity, distractor identity, and display size as factors. Errors were greater in unknown search than known search [$F(1,15) = 5.576$, $p < .05$] and greatest for the small target as opposed to the medium or large target [$F(2,30) = 4.263$, $p < .05$]. There was also a target identity × distractor identity interaction [$F(2,30) = 9.072$, $p < .005$]. As can be seen from Table 1, errors were at least 2% greater in the condition with the small target appearing with medium distractors, at about 8%. For the other display conditions, errors were approximately 5%. No other main effects or interactions approached significance.

Repetition effects for unknown targets. Performance was also broken down as a function of whether targets were repeated across consecutive trials. In this analysis, RTs were summed over distractor identity to ensure there were enough trials in the four carryover conditions. Note that this analysis tends to underestimate the effects of carryover on the endpoint targets relative to the medium target, since carryover effects tend to be smaller when search is easier [in the S(L) and L(S) conditions]. Over consecutive trials, (1) the target and distractor were repeated, (2) the target was repeated but the distractor changed, (3) the target was the distractor on a previous trial, and (4) the target did not appear on the previous trial. A two-way ANOVA with target size and carryover showed main effects of target size [$F(2,30) = 52.615$, $p < .001$] and carryover [$F(3,45) = 21.473$, $p < .001$]. RTs were fastest when both target and distractors were repeated (905 msec) over consecutive trials, relative to when the target was repeated but the distractor changed (981 msec), when the target was a distractor on the previous trial (1,053 msec), and when the

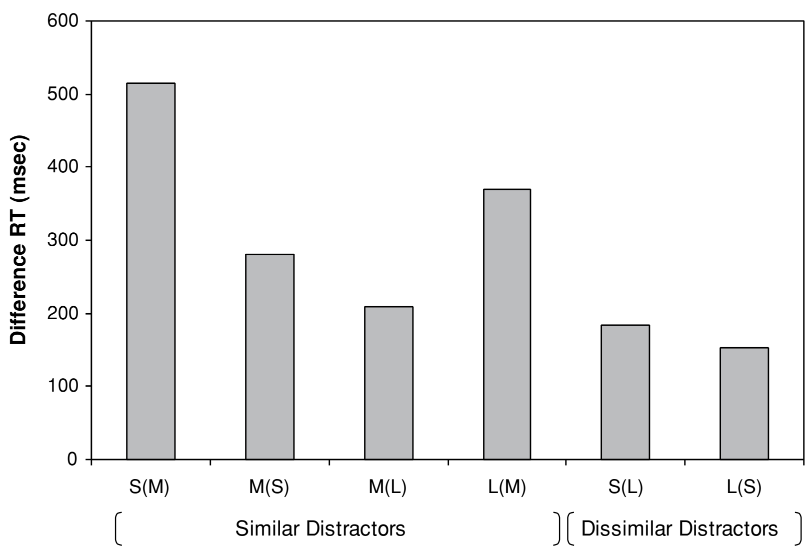

Figure 4. Difference RTs (in milliseconds) for Experiment 1, showing the magnitude of the effect of target foreknowledge (averaged across display size). A positive score indicates that RTs were faster in the foreknowledge condition.

Table 1
Overall Means (in Milliseconds) and Percentage Errors by Display Condition and Known and Unknown Search in Experiment 1

	Display Condition					
Search	S(M)	S(L)	M(S)	M(L)	L(S)	L(M)
Known						
M	878.1	692.3	747.7	774.1	643.1	677.5
%Errors	5.9	4.3	4.6	5.2	5.6	4.7
Unknown						
M	1,393.6	875.5	1,027.6	982.5	795.6	1,046.2
%Errors	9.1	5.3	5.9	6.8	4.6	6.0

target did not appear on the previous trial (1,018 msec). There was a two-way interaction between target size and carryover [$F(6,90) = 7.485$, $p < .001$]. Figure 5 shows that the pattern of carryover effects was different for the three targets. Relative to when the target and the distractor were both repeated, the biggest cost for the medium target was when the distractor identity changed. In contrast, both small and large targets showed a larger cost when the target's identity changed (when the target on trial $n+1$ bore no relation to that on trial n or when the target was previously a distractor), relative to when the distractor identity changed. To investigate this further, separate one-way ANOVAs examining carryover were performed on each target size.

For the small target, there was a main effect of carryover [$F(3,45) = 5.175$, $p < .005$]. Relative to the repeated target and distractor, Bonferroni-adjusted post hoc comparisons showed that RTs were slowest when the target was different on the prior trial (122 msec and 140 msec for previously being a distractor and for previously not being present). It made little difference whether or not the target was a distractor on the prior trial. There was a trend for a cost (63 msec) of changing the distractor across trials while the target remained the same, but this difference was not significant.

For the medium target, there was a main effect of carryover [$F(3,45) = 16.071$, $p < .001$]. The biggest RT cost (135 msec) over repeating the target and the distractor was for switching the distractor's identity while repeating the target. Post hoc comparisons showed that this was significantly greater than switching to the medium target from the small or large target ($p < .01$). There was no significant effect of whether or not the target was a distractor on a previous trial, although these conditions were again slower (77 and 50 msec) than repeating the target and the distractor across trials.

For the large target, there was an overall difference between the conditions [$F(3,45) = 20.588$, $p < .001$]. Repeating the large target and the distractor resulted in a large benefit on RT, both when the target was a distractor on a previous trial (241 msec) and when it was not (148 msec); pairwise comparisons indicated that these effects were significant ($p < .01$). There was, however, little RT cost for changing the distractor while repeating the target (28 msec). As for the medium target, although there was a trend for the participants to be slower when the target was the distractor on a previous trial (93 msec) than when the target was a new item, this difference was not significant.

Discussion

There were several results of interest on RTs. Generally, search was fastest for the large target, followed by the medium target, the small target being slowest. This is consistent with a salience interpretation (Braun, 1994), in which targets larger than distractors are more salient than targets that are smaller than distractors. Search is directed more efficiently to salient targets. Depriving the participants of target knowledge produced a differential impact

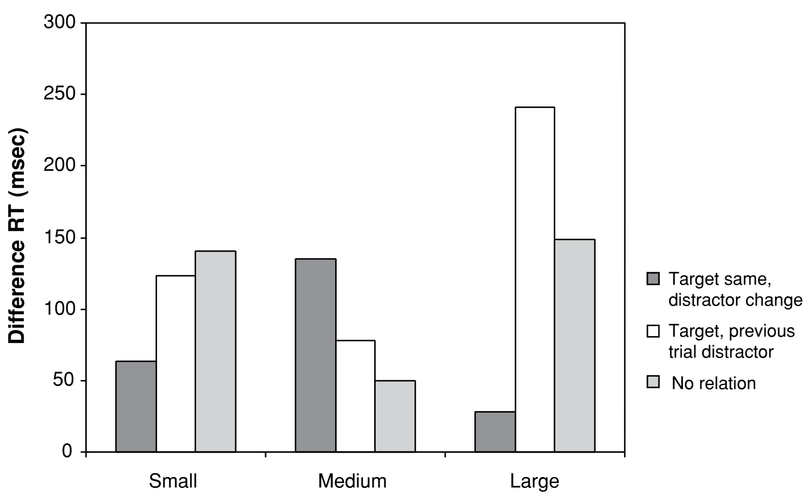

Figure 5. Difference RTs (in milliseconds) for Experiment 1 as a function of whether the target was repeated but the distractor changed, was a distractor on the previous trial, or did not appear on the previous trial, relative to when the target and distractor remained the same over consecutive trials. A positive score indicates faster RTs on repeated trials.

on search. However, the biggest performance benefit from target knowledge was for the small target and the large target. This effect also varied with the similarity of the distractors. Effects of target foreknowledge were smaller when the distractors were less similar to the targets [S(L) and L(S)]. An analysis of errors showed that this was not due to a speed–accuracy trade-off. There were also differential carryover effects across trials. Carryover effects on small and large targets were greatest when the target identity changed (when the targets on trials n and $n+1$ were unrelated, or when the distractor on trial n became a target on trial $n + 1$). In contrast, the primary cost for the medium target was when the target remained the same, but the distractors switched, either from M(S) to M(L) or from M(L) to M(S).

We consider first the effects of target foreknowledge, with large and small targets showing a greater benefit than the medium target. This replicates the data of Hodsoll and Humphreys (2001) despite the fact that, in terms of the display on each trial, the target is always linearly separable from the distractors. It seems that search here is not simply a matter of looking for a smaller or larger target. Foreknowledge that the target is medium does not allow a template for the target to be tuned to optimize search, in comparison with when the target falls at the endpoints of the feature dimension. The effects of foreknowledge are particularly striking for the small target, which may be considered the least salient in bottom-up terms (Braun, 1994). The effects are also more pronounced when the distractors were more similar to the target [e.g., S(M) and L(M)] than when they were dissimilar [e.g., S(L) and L(S)]. Target–distractor similarity effects are reduced when target foreknowledge is applied. This contrasts with how foreknowledge relates to linear separability. When search for linearly separable and nonlinearly separable targets and distractors are compared (Hodsoll & Humphreys, 2001), foreknowledge affects the more salient targets (those linearly separable from the background). Furthermore, foreknowledge effects do not simply map onto the overall salience of the target–distractor pairings. On the salience account of Braun (1994), targets that are more salient than distractors need less attentional guidance than targets that are less salient, and so top-down effects should be smaller on salient targets. This holds for the S(L) and S(M) pairings. In this case, the target was less salient for the S(M) pairing, and the knowledge effect was larger. However, the target in the L(M) pairing should be more salient than that in the M(L) pairing. Despite this, foreknowledge effects were stronger in the L(M) pairing. We suggest that this is because it is easier to set a template at the salient end of the size continuum.

Consider now the effects of carryover of targets across trials. Typically, carryover effects have been attributed to a form of implicit memory formed from the target on trial $n-1$ that influences search on trial n (Hillstrom, 2000; Kristjansson et al., 2002; Maljkovic & Nakyama, 1994, 1996). These accounts stress that the memory is formed automatically from the stimulus rather than reflecting different templates for targets held across trials (although Wolfe, Butcher, Lee, & Hyle, 2003, discuss the effects as being a form of top-down influence on search). Our results strikingly demonstrate that carryover effects from changing the target can reflect differences in top-down processes and do not simply reflect a memory formed in a bottom-up manner from the target on the previous trial. We have found that carryover effects due to target change were strongest for targets at the end of a feature dimension—in particular, for the large target. If there was simply passive carryover of visual memory for the target across trials, then there should have been equivalent repetition effects for the medium target, rather than for the small and large targets. The fact that there was a larger repetition effect for large targets illustrates that the effects were contingent on the memory definition of the target along the dimension and on whether or not this held constant across trials.

Note also that there was an effect of changing the distractor over a previous trial, and not just the target (see also Kristjansson et al., 2002). Interestingly, while the effect of target repetition was largest for the medium target, the effect of distractor repetition appeared to be the largest for the medium target (i.e., relative to when the target and the distractor were the same, RTs were slowed, particularly when the target was constant but the distractor changed across trials). These data have implications for understanding the way that templates may be coded in search. The differential effect of foreknowledge according to the size of the target suggests that the absolute size of the target is specified as part of the template description (the medium target being more difficult). However, the carryover effects due to changing the distractor also indicate that the relative size of the target is also encoded. For example, a target may be denoted as being either *larger than* or *smaller than* the distractors. However, this would introduce some difficulties for a medium target when the distractors change across trials. When the distractors are small, then a medium target would be coded as *larger than*, while the same target would be coded as *smaller than* when the distractors are large. This could reduce benefits from repeating the target.

An alternative explanation has been suggested by A. Kristjansson (personal communication, May 2004). This relates the differential cost of switching distractors for the differing targets to the similarity between the distractor items across trials. Switching across trials between dissimilar distractors [e.g., M(S) to M(L), or small and large distractors] may give more of a decision cost than switching between similar distractors [i.e., small to medium, L(S) to L(M)]. Whether the differing cost relates to categorical switching or similarity to distractors across trials is unclear at this point. Nevertheless, this result does not affect the main finding for carryover effects—that there is a greater cost for switching to endpoint targets than for the medium target. In Experiment 2, we compared performance when participants were given foreknowledge of the specific target against foreknowledge of which parts of a feature dimension would be important (a "not" cue).

EXPERIMENT 2
Top-Down Knowledge via a "Not" Cue

In Experiment 2, the participants were given on each trial a cue specifying which item was not present. Although this trial-by-trial cuing procedure differed from the blocked method of varying target foreknowledge used in Experiment 1, our prior work has indicated that this difference is not critical. Hodsoll and Humphreys (2005) showed that effects of specifying a given target on a trial-by-trial basis had virtually equivalent effects to blocking, when the particular target was indicated.

Method

Participants. Sixteen participants (4 males and 12 females) from the University of Birmingham took part in the experiment for course credit. All had normal or corrected-to-normal vision. Three were left-handed, and 13 were right-handed. The mean age was 20.8 years.

Apparatus, Stimuli, Design, and Procedure. The apparatus, stimuli, design, and procedure were the same as those in Experiment 1. However, in the "not" cue search condition, a "not" target or distractor cue appeared centrally for 500 msec. This cue indicated which item would not appear as the target or the distractor in the following display:

Large. Small target and medium distractors [S(M)] or medium target and small distractors [M(S)].

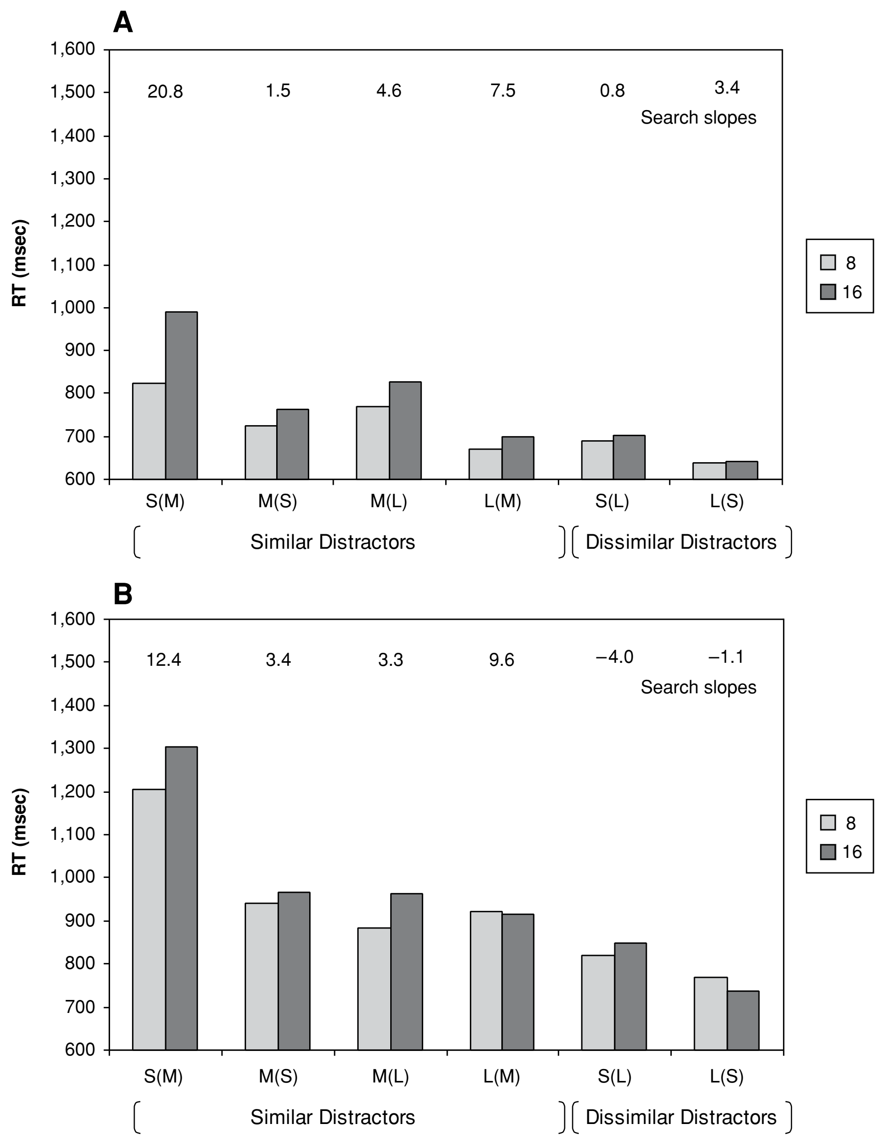

Figure 6. Mean correct RTs (in milliseconds) for the known search condition (A) and the unknown search condition (B) in Experiment 2 as a function of display condition (target size and distractor identity) and display size (8 or 16 items), including search slopes.

Medium. Small target and large distractors [S(L)] or large target and small distractors [L(S)].

Small. Medium target and large distractors [M(L)] or large target and medium distractors [L(M)].

Results

Visual search. Out of 8,889 correct RTs, 211 (2.37%) were removed as outliers. The mean correct RTs for display size, target knowledge, distractor, and target identities are shown in Figures 6A and 6B. RTs were entered into a four-way ANOVA with display size, target knowledge, distractor, and target identity as factors. RTs were slower at the larger display size [$F(1,15) = 28.58$, $p < .001$], and were fastest for the large target (749 msec), followed by the medium target (855 msec) and the small target (923 msec) [$F(2,30) = 110.23$, $p < .001$]. Responses were faster in the known condition than in the known condition [$F(1,15) = 75.23$, $p < .001$]. Distractor identity was significant, but this can only be meaningfully interpreted in terms of its interaction with target identity.

There was a two-way interaction between target and display size [$F(2,30) = 16.07$, $p < .001$], with the greatest effect of display size being for the small target. There was also a target × distractor identity interaction, with the small and large targets showing large RT advantages when they appeared with low-similarity distractors rather than high-similarity distractors. For the small target, RTs were much quicker when it appeared with the large distractors as opposed to the medium distractors. For the large target, RTs were faster when the target appeared with small distractors relative to the medium distractors. In contrast, the difference between RTs for the medium target with the small and large distractors was minimal. There was a trend for display size to interact with target knowledge [$F(1,15) = 3.52$, $p = .08$], and target knowledge interacted with target identity [$F(2,30) = 7.41$, $p < .005$]. As Figure 7 shows, when distractors were similar to the target, the benefit of target knowledge was greatest for the small and large targets. Target foreknowledge benefited the medium target least. This effect was largest with similar distractors.

However, these effects were qualified by a three-way interaction between target knowledge, target identity, and distractor identity [$F(2,30) = 38.98$, $p < .001$]. For the small target, the benefit of target knowledge was greater when it appeared with medium distractors as opposed to when it appeared with large distractors. A two-way ANOVA for small-target RTs with only distractor identity and target knowledge as factors showed a significant two-way interaction [$F(1,15) = 37.65$, $p < .001$]. For the medium target in the known condition, there was an RT advantage when it appeared with the small distractors relative to large distractors. However, there was no such RT advantage in the unknown search condition [$F(1,15) = 14.77$, $p < .001$]. For the large target, RTs were slower when it appeared with medium relative to small distractors. This difference was much greater in the unknown than in the known condition [$F(1,15) = 44.79$, $p < .001$].

Finally, there was also an interaction between target identity, distractor identity, and display size [$F(2,30) = 15.27$, $p < .001$]. The search slope for the small target was much greater when it appeared with medium distractors as opposed to large. For the medium target, search slopes were larger when the target appeared with large distractors than when it appeared with small. However, for the large target, search slopes were approximately the same

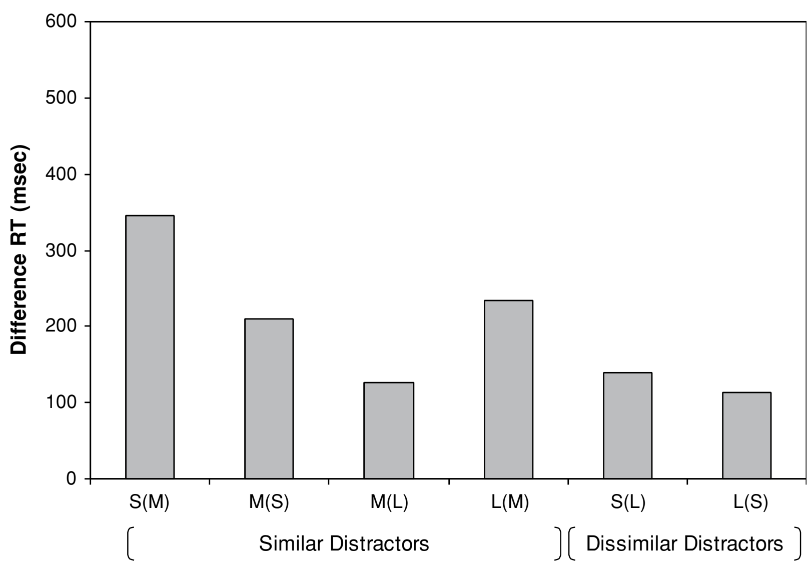

Figure 7. Difference RTs (in milliseconds) for Experiment 2, showing the magnitude of the effect of target foreknowledge (averaged across display size). A positive score indicates that RTs were faster in the foreknowledge condition.

whether the target appeared with the small or medium distractors. None of the other three-way interactions or the highest order interaction reached significance.

Errors (shown in Table 2) were mostly less than 8% and showed only a significant effect of display size [$F(1,15) = 5.632, p < .05$]. Errors were larger at Display Size 16 than at Display Size 8. This indicates that the results were not due to a speed–accuracy trade-off.

Intertrial analysis. A target (small, medium, or large) × carryover (over consecutive trials: the target and distractor were repeated, the target was repeated but the distractor changed, the target was the distractor on a previous trial, or finally the target did not appear on the previous trial). ANOVA was carried out on RTs. Generally, carryover effects were reduced in Experiment 2 relative to those in Experiment 1, but the results followed the same pattern (see Figure 8). There was a main effect of target [$F(2,30) = 65.377, p < .001$] and carryover [$F(3,45) = 9.9298, p < .001$]. RTs were fastest in the two conditions in which the target was repeated relative to when the target changed. More importantly, there was still a significant interaction between target identity and carryover [$F(6,90) = 3.071, p < .01$]. Similar to the carryover effects in Experiment 1, the biggest carryover effects were associated with the endpoint targets and, in particular, the endpoint targets when the target was constant across trials.

For the small target, although RTs were faster when the target was repeated as opposed to when it changed (Figure 8), this effect was present only as a trend [$F(3,45) = 1.652, p < .2$]. Similarly, for the medium target, RTs showed a trend to be faster only when the target and the distractors were repeated, relative to when only the distractors and when both the target and distractors were changed [$F(3,45) = 2.638, p < .07$]. For the large target, there was a significant effect of carryover [$F(3,45) = 20.427, p < .001$]. Bonferroni-adjusted pairwise comparisons showed that, when compared with the condition in which both the target and the distractor were constant, repeating the target but changing the distractor had no effect on RTs. In contrast, changing the distractor had a large effect on RT, whether or not the target was a distractor on the previous trial (169 and 106 msec, respectively).

Between-experiments analysis. To compare visual search performance between Experiments 1 and 2, a mixed five-way ANOVA with experiment as a between-participants factor was carried out. Only those factors tied with experiment are reported in this section. For RTs, there was no main effect of experiment, but there was a two-way interaction between experiment and target knowledge [$F(1,30) = 5.53, p < .05$]. The "not" cue used in Experiment 2 reduced the benefit of target knowledge by 90 msec. None of the other two-way or three-way interactions was significant. There was a four-way interaction between target knowledge, target identity, distractor identity, and experiment [$F(2,60) = 7.37, p < .005$], illustrated in Figure 9. The difference between the experiments was most pronounced for small targets presented among medium distractors and for large targets presented among medium distractors. For both the small and large targets only, there were interactions of distractor identity, target knowledge, and experiment [$F(1,30) = 7.17, p < .01$ for the small target, and $F(1,30) = 10.01, p < .005$ for the large target]. There was no effect of experiment on the medium target. Note also that there was no effect of experiment on errors.

Table 2
Overall Means (in Milliseconds) and Percentage Errors By Display Condition and Known and Unknown Search in Experiment 2

Search	Display Condition					
	S(M)	S(L)	M(S)	M(L)	L(S)	L(M)
Known						
M	908	695	743.5	798	640	684.5
%Errors	6.4	4.4	7.0	5.0	5.3	5.5
Unknown						
M	1,253.5	834.5	954	923.5	753	918.5
%Errors	7.2	6.3	5.6	5.7	4.3	7.4

Discussion

The pattern of the results in Experiment 2 was broadly similar to that found in Experiment 1. There was a beneficial effect of foreknowledge, even though we specified only which items the display would not contain, rather than specifying the actual target. Analysis of errors showed this was not due to a speed–accuracy trade-off. We suggest that this beneficial effect arose because the "not" cue enabled the participants to set a template to a restricted part of the size feature dimension. As for blocked presentations in Experiment 1, this beneficial effect was strongest for the targets at the end of the feature dimension (small and large targets), particularly when there were similar distractors. There were also differential carryover effects across trials, with repetition effects being strongest for the large target and minimal for the medium target. Over and above this, the size of the benefit from foreknowledge was smaller than when the participants knew the exact target identity on each trial.

The similarity of the pattern of performance across the present experiments emphasizes the robustness of the findings. We suggest that there are substantial effects of participants being able to set a template for search even with stimuli that differ by a single feature contrast (size). Furthermore, these template effects are sensitive to variations along the feature dimension across trials. Medium targets benefit less than do targets at the end of the feature dimension, because it is more difficult to tune a template to midpoint values in a continuum (even though the medium targets were the smallest or largest items in the field, on any given trial).

GENERAL DISCUSSION

We have reported two experiments demonstrating effects of foreknowledge on search for targets defined along the size dimension. In the present experiments, only two types of stimuli were exposed on each trial (the target plus a homogeneous set of distractors), so that the target was

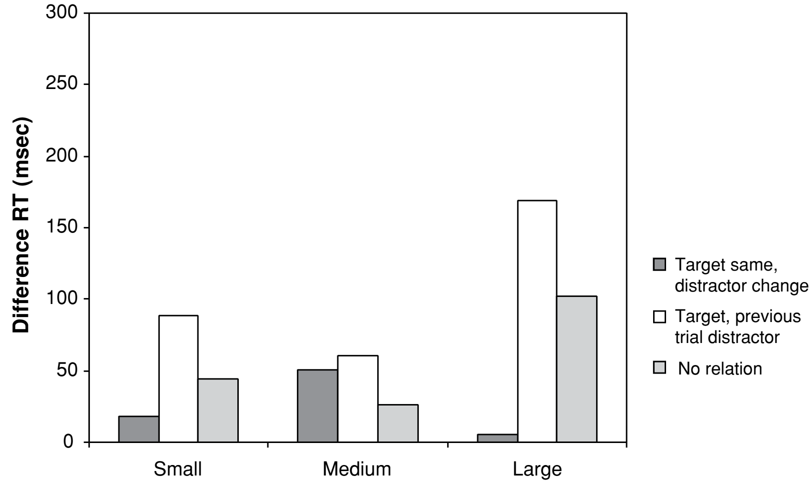

Figure 8. Difference RTs (in milliseconds) as a function of whether the target was repeated but the distractor changed, was a distractor on the previous trial, or did not appear on the previous trial, relative to when the target was repeated in Experiment 2. A positive score indicates faster RTs on repeated trials.

always specified by a simple feature value relative to the distractors (larger or smaller in size). Replicating prior data when targets were presented with heterogeneous distractors, we found differential effects of foreknowledge on search. Foreknowledge facilitated search more for targets that fell at the extremes of the feature dimensions (for small and large targets) than for targets that fell at the midpoint (medium targets). The facilitatory effect was strongest when the distractors were similar to the targets. In addition, there were differential priming effects when the targets were carried over across trials. When the targets were repeated, large stimuli benefited most, with the next largest benefit being for small stimuli. There was minimal benefit for repeating medium targets across trials. This pattern of results occurred both when foreknowledge was not given for a specific object on the trial (Experiment 1) and when the participants were given knowledge of which size of stimulus would not be present (Experiment 2). However, the foreknowledge effects were reduced in the latter case.

The data indicate the pervasive effects of providing foreknowledge on search for feature-defined targets. The

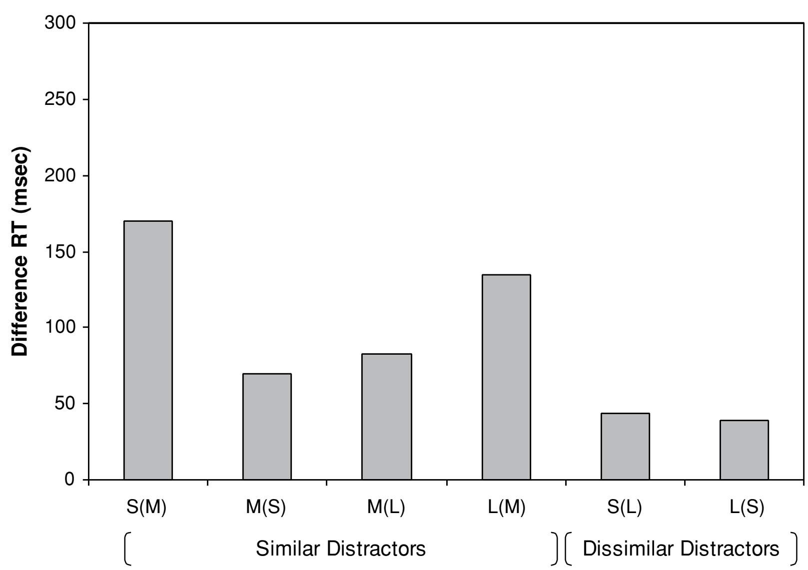

Figure 9. The RT effect of the "not" cue—that is, the RT difference (in milliseconds) between the unknown conditions in Experiment 1 and Experiment 2, by target size and distractor identity.

fact that the effects were strongest on targets at the ends of the feature dimension is consistent with the foreknowledge effects being based on matches to a target template, with the template being easier to tune to the ends of a dimension. Medium targets may suffer because there is greater uncertainty associated with coding the absolute size of this target. In addition, any specification of the relative size of the medium target (larger than or smaller than the distractors) may change across trials.

In accord with this, we found costs to any carryover effects when the distractors changed over consecutive target trials; in contrast, when the target was large or small, costs on carryover effects reflected switches of the target. We also suggest that there is a distinction between the effects of foreknowledge on setting a template and the effects of the template on modulating similarity and salience relations between stimuli in the field. Template effects influence targets at the ends of a dimension, even if the targets are relatively high in bottom-up salience (e.g., the large targets here). Once established, however, any effect of the template emerges more strongly when the distractors are similar to the targets and they are less salient (e.g., the small target with medium distractors here). Presumably, this is because the template enhances the processing of the target relative to that of the distractors, reducing similarity and absolute saliency effects between the items in the field (see Bundesen, 1990, for one detailed account). This in turn suggests that factors that influence template setting (including the linear separability of target and distractors; Hodsoll & Humphreys, 2001) can be distinguished from template effectiveness. Templates are difficult to set for nonlinearly separable targets, but they can be set up for linearly separable targets, and, in this case, they help the detection of less salient items in particular.

However, although we have discussed these results in terms of the tuning of templates, we may also think of these effects as being due to the setting of a decision boundary. With a large or small target, a decision boundary could be set at one end of the feature continuum, and this could be held constant across trials when the target was known. When the target was unknown, performance would be little affected by whether the distractor changed (from medium to small, or vice versa), provided the target stayed the same, since the decision boundary could still be set at the end of the continuum and each distractor would be rejected. For the medium target, the decision boundary would need to be switched to different parts of the feature space according to whether the distractors were small (decision boundary between small and medium) or large (decision boundary between large and medium). Whether or not a template or decision-boundary account is maintained, the important point is that search for apparently salient (large or small) targets is affected by top-down knowledge.

The present results also have implications for understanding carryover effects in visual search. Usually, such carryover effects have been attributed to an implicit memory specific to the target on the preceding trial (Hillstrom, 2000; Maljkovic & Nakayama, 1994, 1996). However, our data suggest that this is not the case, since, otherwise, there should have been equivalent repetition effects with medium targets when they reoccurred on consecutive trials. There was no indication that this was the case. Instead, we propose that feature-based repetition effects reflect, at least in part, the trial-by-trial setting of a template. This template is affected by the history of prior trial and more difficult to tune for middimension targets.

Finally, we can speculate about whether the dimensions of the features used in search are set within an experiment (e.g., dimensions are set to the range of features present) or whether they are relatively more absolute (e.g., are fixed small and large ends of a feature dimension). Further work is required to distinguish these possibilities.

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