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Driving attention with the top down: The relative contribution of target templates to the linear separability effect in the size dimension

JOHN HODSOLL and GLYN W. HUMPHREYS
University of Birmingham, Birmingham, England

Bauer, Jolicœur, and Cowan (1996a, 1996b, 1998) have shown that visual search for a target among distractors is apparently serial if the target is nonlinearly separable from the distractors in a particular feature space (e.g., color or size). In contrast, if the target is linearly separable from the distractors, search is relatively easy and seemingly spatially parallel. We examined the contribution of top-down knowledge of the target to the linear separability effect on search. Two visual search experiments were conducted using small, medium, or large circles as targets. In the first experiment, participants could use knowledge of the target to guide search, whereas, in the second, the target was unknown on each trial. Search for a medium (nonlinearly separable) target among small or large distractors benefited least from knowledge of the target as compared with search for a small or large target. Thus, the linear separability effect can be determined in part by use of top-down knowledge to facilitate the detection of targets at the ends of a continuum defining the stimuli.

Recent research has shown that the difficulty of visual search can be dependent on whether a target is or is not linearly separable from the distractors within a particular feature space (D'Zmura, 1991). The effect of linear separability has primarily been investigated in color space. If, as in Figure 1A, the target and distractors are linearly separable, search appears to be relatively easy and spatially parallel. There can be minimal effects of the number of distractors on search. In contrast, if, as in Figure 1B, the target and distractors are nonlinearly separable, search appears to be serial in nature. There are linear effects of the number of distractors on search and present:absent search ratios approximate 1:2, as predicted by a serial self-terminating search mechanism (e.g., see Treisman & Gelade, 1980; though see Humphreys & Müller, 1993, and Townsend, 1990, for alternative accounts).

Bauer, Jolicœur, and Cowan (1996b) replicated and extended this finding. They established that the linear separability effect consisted of difficult search for nonlinearly separable targets, was subject to boundary conditions; for instance, if the distractors were far enough away from the target, in color space, then search was parallel, whether or not the target and distractors were linearly separable in feature space. However, once target and distractors are sufficiently close within feature space, so the contrast between quasi-linearly separable and nonseparable search increases continuously, as the condition of full separability is approximated. Thus, rather than there being a qualitative difference between the linearly separable and nonlinearly separable search conditions there was a continuum of search difficulty that depends on how near the criterion of linear separability was to being satisfied.

D'Zmura (1991) and Bauer et al. (1996b) explained the linear separability effect in terms of search being mediated by a chromatically linear filter mechanism, which can be applied across a search display in a spatially parallel manner. If targets and distractors are linearly separable, this mechanism can detect a target–distractor difference in parallel across the display. However, if the stimuli are not linearly separable, the target cannot be detected in this manner. Search will then depend on a serial process of attentional selection of each item in turn. Investigation of other feature domains, such as luminance (Bauer, Jolicœur, & Cowan, 1996a) and size (Wolfe & Bose, 1991) suggests that search can be mediated by a linear mechanism within the relevant dimension, which can detect, in a spatially parallel manner, targets that are linearly separable from distractors. Thus, in the size domain, search for small or large targets can be relatively efficient, whereas search for medium targets is inefficient and apparently spatially serial.

This view of linear separability on search stresses the role of bottom-up factors in determining search efficiency.

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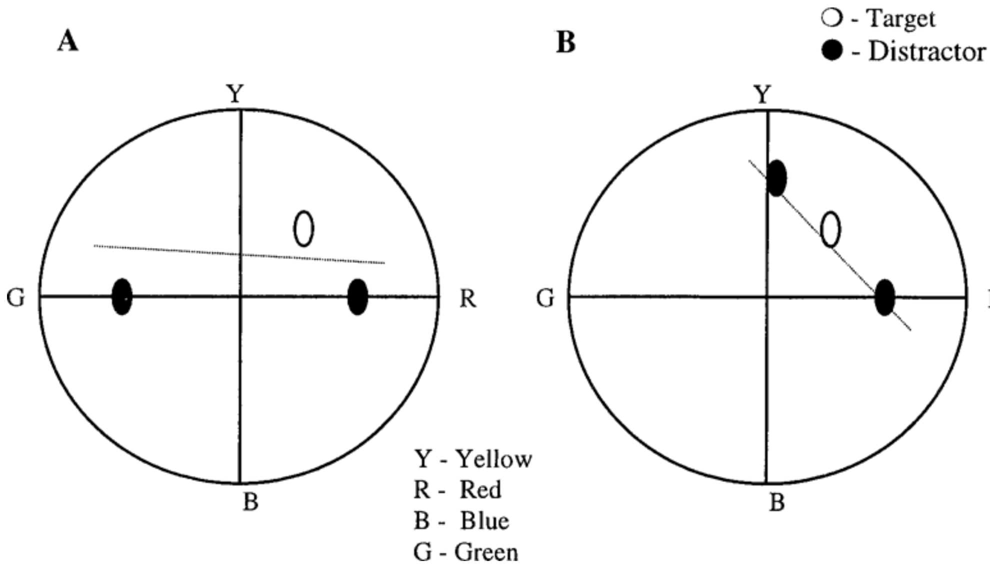

Figure 1. Examples of linearly and nonlinearly separable targets in color space.

However, current models of visual attention propose a role for top-down as well as bottom-up factors. We take *bottom-up* to mean that target–distractor differentiation is mediated by stimulus-driven processes, detected by low-level perceptual input systems. By top-down processes we mean that the perceptual system can be set by instruction, so that target–distractor differentiation is facilitated. In other words, in addition to any bottom-up effects, top-down processes can modulate selection by "tuning" the perceptual system to particular feature input values. Such tuning effects may be brought about either by amplifying target feature values or inhibiting nontarget feature values (cf. Guided Search 2.0, Wolfe, 1994; *revised feature integration theory*, Treisman & Sato, 1990; *attentional engagement theory*, Duncan & Humphreys, 1989). The effectiveness of top-down processes depends, at least in part, on whether activation or inhibition can be limited to the set of target or nontarget items, respectively. This is likely to be determined by the similarity between target and distractor items. For example, top-down inhibition of pink distractors would be more likely to affect detection of a red target than would top-down inhibition of green distractors. In addition, the similarity between distractors will also be important. The more similar distractors are to each other and the more different to targets, the more top-down activation and/or inhibition can be applied selectively across all distractors in a display (see Duncan & Humphreys, 1989).

The linearly separable constraint adds another theoretical consideration over and above similarity in the interpretation of search behavior. Indeed, Bauer et al. (1996b) contend that many color visual search results explicated in terms of similarity relations could actually be due to target and distractors being nonlinearly separable. For example, the target and distractors in the heterogeneous distractor condition of Duncan (1989) were nonlinearly separable. (We shall return to the issue of linear separability vs. similarity in the General Discussion section.) In the present study, we ask whether the filter mechanism responsible for the linear separability effect is largely the provenance of top-down or bottom-up processes.

A previous paper by Olds, Cowan, and Jolicœur (1999) is relevant here. They manipulated the uncertainty of possible distractor pairs while keeping target identity constant. For a given target, three distractors were chosen that, when all present, would render the target nonlinearly separable. The presence of only two types of distractors would allow linear separability to be maintained. On any given trial, any three of the possible distractor pairs could make up the nontarget set. Olds et al. reasoned that if top-down modulation of search was critical, search should be impaired under these conditions of uncertainty, relative to when the distractors were known in advance. It was found that, although there was an overall slowing of response in the uncertain condition, there was no indication of an increase in search difficulty measured in terms of search slopes. It is difficult to make a strong conclusion from this result, however. As Olds et al. point out, it may be that representations of the distractors can be set-up in advance. These can then be applied rapidly in a top-down manner, even under uncertain distractor conditions.

Given that when the target is known, the correct linear separator may be adopted by a rapid identification of the distractors present, manipulating target rather than distractor certainty may be a more effective way of dissociating top-down and bottom-up processes. If the linear separability operator is largely bottom up, foreknowledge of the target should have little differential impact on the search for linearly separable and nonlinearly separable targets. If the operator is set in a top-down manner, fore-

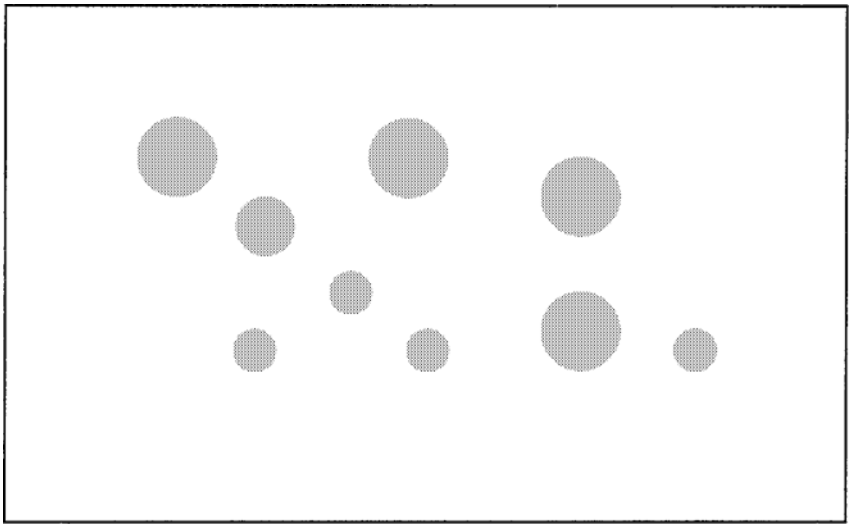

Figure 2. Example of a search display with a medium circle as the target.

knowledge of the target should facilitate search for linearly separable targets and distractors, relative to when targets and distractors are not linearly separable.

To test these predictions, we manipulated target certainty in tasks requiring search for linearly separable and nonseparable targets and distractors. Stimuli varied along the size dimension, which Wolfe and Bose (1991) showed behaves similarly to the color dimension in generating effects of linear separability. In Experiment 1, search was either for a small, medium, or large target among, respectively, medium and large, small and large, or small and medium distractors. Each target was presented over a block of trials, thus favoring the use of a target template. In Experiment 2, participants had no knowledge of the particular target on a given trial. Instead, the target was defined by being a singleton in the display (i.e., a stimulus with a unique size relative to the other items present). If top-down knowledge of the target is important for the standard linear separability effect (when the target is known), the detection of linearly separable targets should suffer differentially under singleton search conditions (i.e., the detection of large or small targets when compared with that of the nonlinearly separable medium target).

EXPERIMENT 1
Search for Known Targets

In Experiment 1, we investigated search performance for three circles: small, medium, and large. The aim was to establish the linear separability effect for the stimuli used under conditions in which the target was known—that is, when top-down guidance of search was optimal.

Method

Participants. Twelve university students took part in the experiment, 4 males and 8 females, aged 18–24 years. All had normal or corrected-to-normal vision. Course credits were given for participation.

Apparatus. All experiments were programmed using MEL v2.01 running on a Pentium II/350 MHz computer with a Gateway 15-in. 500CS monitor driven by an STB Velocity 128 graphics card.

Stimuli. The stimuli consisted of three circles with diameters of 0.61°E, 0.84°E, and 1.22°E visual angle (at distance of 0.75 m), classified as small, medium, and large, respectively. On a 640 $\times$ 480 VGA display, the individual stimuli subtended areas of 314, 616, and 1,520 pixels, the difference between the medium and small circles being a quarter of the difference between the large and small circles. The stimuli appeared as cyan or light blue (defined as palette 11 in MEL) on a black background. The display was divided into a 5 $\times$ 5 array, each location being 50 pixels square. Within each array location, display elements were randomly offset from the center point by 1–5 pixels. A typical search display is shown in Figure 2. 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 25 possible locations.

Design. The experiment comprised four conditions: (1) target size, defined as large, medium, or small, (2) number of display elements 5, 7, 9, (3) target present/absent, and (4) distractor ratio, a balancing condition that is not considered in the subsequent analysis. This was necessary since there was an odd number of distractors in the target-absent display conditions.

The target size condition was blocked, with each participant's being assigned to different blocks in random order. The other four experimental conditions were mixed randomly within each block. There were 12 presentations of each display for each variation of number of elements, target size, target present/absent, and distractor ratio, making a total of 432 trials.

Procedure. The participants were seated approximately 0.75 m from the display screen. At the beginning of each block, an introductory screen showed the participants the particular target and distractors for that block. The participants commenced each block when they considered themselves to be ready. On each trial, a fixation cross appeared for 400 msec followed by a search array that was displayed until a response was made. For 50% of the participants, the target-present response key was "z" and the target-absent key was "m"; for the other 50%, the response keys were reversed. The maximum allowed response time was 30 sec. To help maintain

Table 1
Mean Correct RTs (in Milliseconds) by Target Size, Target Presence, and Display Size in Experiment 1

Target	Display Size 5	7	9	Slope	r^2%	Intercept
Small						
Present	562	570	585	5.74	97.1	533
Absent	609	632	650	10.2	99.3	559
Medium						
Present	746	823	849	25.7	92.7	626
Absent	839	933	1103	66.0	97.3	497
Large						
Present	513	515	524	2.79	90.4	498
Absent	565	575	586	5.19	99.8	539

motivation, the participants were given feedback on each trial (whether their last response was correct or not). There was an intertrial interval of 750 msec. Before commencing the experiment proper, all participants were given a practice set of at least 48 trials containing all experimental conditions.

Results

Reaction times. A modified recursive outlier elimination procedure with moving criterion (Van Selst & Jolicœur, 1994) removed 6 out of 5,005 correct reaction times (RTs) (less than 0.2%). Table 1 summarizes the RT data for correct trials only, as a function of target presence/absence for each target type and display size and presents a least squares linear regression analysis for target search functions across display sizes 5, 7, and 9. Note that the slopes for both present and absent responses in the medium target condition (25.7 and 66.0 msec per item) were much greater than in the small and large target conditions (see Figures 3A, 3B, and 3C). The present/absent slope ratio for the medium target, at 1:2.5, is broadly consistent with a serial self-terminating search process.

A three-way analysis of variance (ANOVA) was conducted with target presence, target size, and display size as factors. RTs for the medium target (882 msec) were significantly longer than for small (601 msec) or large targets (546 msec) [$F(2,22) = 95.01, p < .001$]. Target-present trials (617 msec) were faster than target-absent trials (663 msec) [$F(1,11) = 24.33, p < .001$], and RT increased with display size and for five (616 msec), seven (653 msec), and nine (689 msec) [$F(2,22) = 61.88, p < .001$] elements.

All two-way interactions were also significant; the increase in RT with display size was greater on the absent than on the present trials [$F(2,22) = 11.96, p < .001$]. RTs also showed a greater increase with display size for the medium target but not for the small or large targets [$F(4,44) = 28.25, p < .001$]. The advantage in RT for target-present trials as compared with target-absent trials was greater for medium targets than for small or large targets [$F(2,22) = 7.16, p < .005$]. Finally, the highest order interaction was significant [$F(4,44) = 6.44, p < .001$]. This resulted from there being a greater difference in the target present/absent search slopes for the medium target relative to the small or large targets.

Error analysis. Table 2 shows the percentage error rates according to target type, target presence, and display size. A three-way within-subjects ANOVA (with factors as in the RT analysis above) was performed using the number of correct responses as the dependent variable. The participants made more errors as display size increased [$F(2,22) = 1.27, p = .301$], and they were more likely to miss targets than to report false alarms [$F(1,11) = 11.23, p < .01$]. Error rates were higher for the medium target than for the small or large targets [$F(2,22) = 5.95, p < .01$].The missed target to false alarm ratio was unaffected by display size [$F(2,22) = 0.53, p = .597$].

The participants were more likely to miss medium size targets than small or large targets, and false alarm rates were fairly consistent across all three target sizes [$F(2,22) = 14.53, p < .001$]. Error rates were greater at smaller display sizes for the medium target but relatively unaffected by display size for the small and large targets [$F(4,44) = 2.79, p < .05$].

Lastly, the three-way interaction between display size, target type, and target size was significant [$F(4,44) = 4.08, p < .01$]. For the medium target, the participants were less likely to miss targets at the higher display sizes, and the false-alarm rate remained approximately the same. This suggests that the participants increased their decision thresholds for present judgments as the difficulty of the search task increased. In terms of the RT analysis, this probably means that, for the medium target condition, the present and absent search slopes are slightly higher than they would be for equal present/absent decision thresholds.

Discussion

As predicted, search for a medium target was considerably more difficult than search for a small or large target. The search rates for the medium target on present and absent trials were broadly consistent with search being spatially serial (Treisman & Gelade, 1980; see also Wolfe, 1998). In contrast, both small and large targets generated behavior characteristic of spatially parallel search; response latencies were approximately 10 msec per item or less for present and absent responses for small and large targets. This pattern of data would be expected if search was contingent on the operation of a linear filter mecha-

Table 2
Percentage Errors by Target Size, Target Presence, and Display Size in Experiment 1

Target	Display Size 5	7	9
Small			
Present	2.1	2.4	4.5
Absent	3.5	2.8	2.1
Medium			
Present	11.1	10.1	5.2
Absent	3.5	0.7	1.4
Large			
Present	2.4	2.1	1.7
Absent	3.5	2.8	2.4

Table 3
Mean Correct RTs (in Milliseconds) by Target Size, Target Presence, and Display Size in Experiment 2

	Display Size					
Target	5	7	9	Slope	r^2%	Intercept
Small						
Present	921	879	885	−8.85	61.4	957
Absent	804	843	860	14.1	95.1	738
Medium						
Present	895	921	944	12.2	99.8	835
Absent	894	1007	1102	51.9	99.8	638
Large						
Present	891	920	918	6.90	70.1	861
Absent	850	889	943	23.4	99.2	730

nism in the size domain. This mechanism should be able to differentiate large and small targets but not intermediate or medium targets. As a consequence, medium targets might only be detected following a spatially serial, attentional search (see also Wolfe & Bose, 1991).

EXPERIMENT 2
Search for Unknown Targets

In Experiment 1, it was possible that search was largely under the guidance of top-down processes; the participants could have used knowledge of the target identity to facilitate search. In Experiment 2, we tested this by examining search behavior (for the same participants) with the same stimuli, but under conditions in which the target was not known prior to each trial. On each trial the target could be a small, medium, or large item, and was defined by having a unique size within the display.

Method

Unless otherwise mentioned, the method was the same as for Experiment 1.The experimental design was similar to that in Experiment 1, with the exception of target size varying randomly on each trial. The participants were instructed to make a present/absent judgment according to whether there was a stimulus of a unique size in the display. Otherwise, trials proceeded as in Experiment 1.

Results

Reaction times. A modified recursive outlier elimination procedure with moving criterion (Van Selst & Jolicœur, 1994) removed 4 out of 4,892 correct RTs (less than 0.1%). Table 3 summarizes the RT data for correct trials only, as a function of target presence and absence for each target type and display size. A regression analysis on target search functions is also presented. A full discussion of search slopes is given in the between-experiments analysis below.

A three-way ANOVA was conducted with target size, target presence, and display size as factors. RTs were slower for medium targets (960 msec) than for small (865 msec) or large (901 msec) targets [$F(2,22) = 19.06$, $p < .001$], and RTs increased as display size increased, from five (876 msec), seven (910 msec), to nine (942 msec) [$F(2,22) = 25.67$, $p < .001$]. Target-present (908 msec) and absent (910 msec) RTs did not differ significantly [$F(1,11) = 0.04$, $p > .8$].

The increase in RT with display size was mainly confined to target-absent trials [$F(2,22) = 18.60$, $p < .001$], and was greater for the medium target than for the small or large targets [$F(4,44) = 9.51$, $p < .001$]. Present and absent RTs differed according to the type of target [$F(2,22) = 14.53$, $p < .001$]. For the small target, target-present RTs were slower than target-absent RTs; for the medium target, target-present RTs were faster than target-absent RTs, whereas for the large target, present and absent RTs were approximately the same. The three-way interaction between target size, display size, and target presence just reached significance [$F(4,44) = 2.67$, $p < .045$]. Although the target present to absent slope ratios were approximately 1:4 for the medium and large targets, for the small target, the slope for target-present trials was negative but positive for the target-absent trials.

Errors. The percentage error rates per target condition are shown in Table 4. The number of correct responses were entered into a three-way ANOVA with target size, target presence, and display size as factors. The participants were more likely to miss targets (6.7%) than to make false alarms (4.7%) [$F(1,11) = 9.58$, $p < .05$]. The participants also made most errors in search for medium targets (8.0%) as opposed to small (4.1%) and large targets (5.0%) [$F(2,22) = 5.19$, $p < .05$]. However, error rates were not affected by display size [$F(2,22) = 0.25$, $p > .75$]. None of the interactions reached significance.

Between Experiments Analysis

Reaction times. To compare Experiments 1 and 2 statistically, all RTs were entered into a four-way ANOVA with target size, target presence, display size, and experiment as factors. To balance the display size factor, RTs for display size one were removed from Experiment 1. Only those effects with experiment as a factor are relevant here.

Responses were significantly slower in Experiment 2 (909 msec) than in Experiment 1 (677 msec) [$F(1,11) = 73.86$, $p < .001$]. Importantly, the cost in RT was significantly less for medium targets (79 msec) than for small (264 msec) or large (356 msec) targets [$F(2,22) = 81.30$,

Table 4
Percentage Errors by Target Size, Target Presence, and Display Size in Experiment 2

	Display Size		
Target	5	7	9
Small			
Present	6.6	4.5	4.5
Absent	1.7	3.1	4.2
Medium			
Present	7.3	12.2	11.1
Absent	4.5	6.3	7
Large			
Present	8	3.8	2.4
Absent	4.9	3.5	7.3

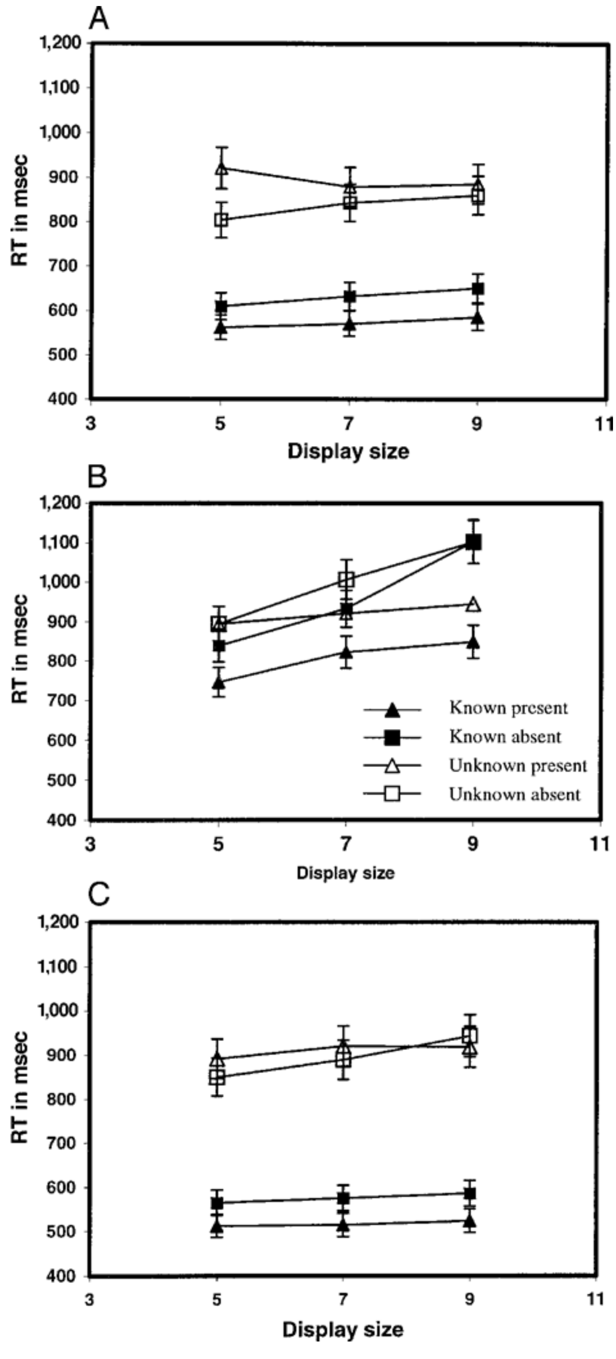

Figure 3A. Small target: known versus unknown search functions for target present and absent. B. Medium target: known versus unknown search functions for target-present and target-absent. C. Large target: known versus unknown search functions for target present and absent.

$p < .001$]. Furthermore, the RT cost affected present RTs (264 msec) more than absent RTs (194 msec) [$F(1,11) = 22.61, p < .001$]. Although RT was generally slower, the increase in RT by display size was not significantly different between the experiments [$F(2,22) = 0.90, p > .4$].

In Experiment 2, as opposed to Experiment 1, RT slopes decreased overall for the small and medium targets, but increased for the large target [$F(4,44) = 4.65, p < .005$] for the interaction of target type, display size, and experiment. There was also a decrease in the effect of display size on RT for the target-present trials from Experiment 1 to Experiment 2 but not for target-absent trials [$F(2,22) = 4.73, p < .05$]. Although target-absent trials were faster than target-present trials for the small and large targets in Experiment 2, but not Experiment 1, this effect failed to reach significance [$F(2,22) = 1.79, p > .15$]. The four-way interaction between experiment, target size, target presence, and display size just failed to reach significance [$F(4,44) = 2.40, p = .065$].

To compare the experiments specifically in terms of search difficulty, a direct comparison of search slopes was done across the two experiments. Figure 4 shows the slope differences for each target condition across the two experiments (a positive value means a larger slope in Experiment 2 than in Experiment 1). First, consider target-present trials. The slope for the small target decreased from 5.74 msec per item to −8.85 msec per item from Experiment 1 to Experiment 2 [$t(11) = 2.55, p < .05$]. For the medium target, the search slope decreased from 25.7 msec per item to 12.15 msec per item [$t(11) = 2.30, p < .05$]. Search slopes increased from 2.79 msec per item (Experiment 1) to 6.9 msec per item (Experiment 2) for the large target; however, the latter increase was insignificant [$t(11) = -0.67, p > .5$]. For target-absent trials, the small and medium targets showed no significant difference between experiments. On the other hand, the large target showed a four-fold increase from 5.19 msec per item to 23.4 msec per item [$t(11) = -3.34, p < .01$].

Errors. A similar between-experiments analysis was performed on errors. In general, the participants made fewer errors in Experiment 1 (3.6%) than in Experiment 2 (5.7%) [$F(1,11) = 12.55, p < .01$]. There was a significant three-way interaction between experiment, target size, and display size [$F(4,44) = 3.74, p < .05$]. For the medium target, accuracy increased with display size in Experiment 1 but decreased with display size in Experiment 2. The highest order interaction also just reached significance [$F(4,44) = 2.57, p = .05$]. This is perhaps largely due to the fact that in Experiment 1, medium target misses decreased from 11.1% to 5.2% as display size increased from five to nine, whereas in Experiment 2, medium target misses increased from 7.3% to 11.1%.

Discussion

Search performance in Experiment 2 was very different from that found in Experiment 1. First, RTs were overall much slower (232 msec). This particular result is not surprising given that target identity was uncertain on each trial. More interestingly, the RT cost was less for the medium target (79 msec) than for the small (264 msec) or large (356 msec) targets. In comparing the error rates between experiments, the percentage increases in errors for the small (1.2%) and large (2.5%) targets were slightly

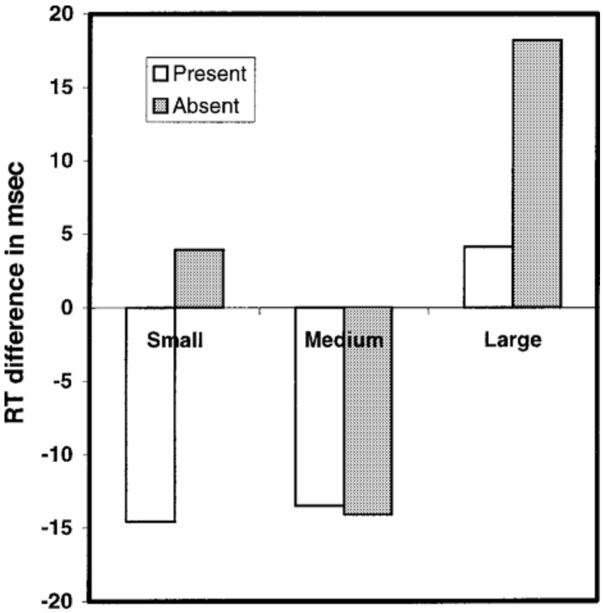

Figure 4. Mean difference in RT (in milliseconds) search slopes between Experiment 1 and Experiment 2 for target size and target present or absent.

less than for the medium target (2.7%). As this difference was not significant, the relatively smaller RT cost for the medium target was not likely to be due to a speed–accuracy trade-off. The data does suggest, however, that top-down guidance of search was less beneficial for the medium target than for the small or large target. The evidence for contrasting effects of target uncertainty on the small and large targets is consistent with the idea that top-down knowledge has a differential impact on targets that are linearly separable from distractors rather than on targets that are not linearly separable. That is, when participants know the identity of the target, some sort of top-down filter can segment a small target from medium and large distractors and a large target from small and medium distractors but not a medium target from small and large distractors.

In addition to the differential effect of singleton search on small and large targets, Experiment 2 generated an interesting change in the search functions. In particular, search slopes in the target-present condition were negative for the small target; they showed a 12 msec per item decrease for the medium target, but increased by 4 msec per item for the large target. Target-absent trials remained approximately the same for the small target, decreased by 10 msec per item for the medium target, and increased by almost 20 msec per item for the large target, with only the latter being statistically significant. One should note, however, that differences in the error rates for the medium target-present condition across display size suggest that the medium target-present slope should have been slightly lower in Experiment 1, but slightly higher in Experiment 2. The change in search slopes contrasts with that of Olds et al., who found that display certainty slowed overall RT, but did not increase RT dependence on set size. The difference here might be that, in Experiment 2, target identity was uncertain as well as distractor identity. This point is considered further below.

The reduction in search slopes for the small and medium targets might follow from the fact that Experiment 2 was not necessarily a simple detection task. Rather, participants may have to identify what the target is before they decide whether a target is present in the display. This identification process might be facilitated by the grouping of distractors on the basis of their common size. Larger groups of distractors might group together more strongly, not least because the distractors will be closer together (cf. Bundesen & Pedersen, 1983, for evidence of grouping by proximity). Hence, this grouping should benefit the small target more rapidly than the medium or large target, as medium and large distractors will form stronger groups than will small distractors. This is consistent with the negative search slopes for small targets. Similarly, Bravo and Nakyama (1992) found negative search slopes for an attentionally demanding search task. Another possibility is that a serial sampling process is involved. As more items in the display are sampled serially, so a template for the target can be progressively established, since even in the singleton task, distractors can be identified after more than two items of the same size are coded on a trial. With larger display sizes, the chances increase that distractors will be sampled rather than the target, facilitating development of the target template (and subsequent RTs).

Another point is that, in Experiment 1, search asymmetries were apparent with the large targets' being detected before the small ones. However, in Experiment 2, search was fastest for the small targets (see Table 3). This result is consistent with the argument we have put forward for the effect of grouping on search slopes (i.e., that target detection is more effective if grouping between distractors is stronger) and/or for the effects of distractor size on attentional switching.

GENERAL DISCUSSION

The present results unambiguously show that top-down processes can influence the linear separability effect in visual search. Experiment 1 showed that search was fast and parallel for the small and large (linearly separable) targets but slower and serial for the medium (nonlinearly separable) target when the target was known across a block of trials (see also Bauer et al., 1996a, 1996b, 1998; D'Zmura, 1991; Olds et al., 1999). On the other hand, with unknown targets, search was slow under both the linearly separable and nonlinearly separable conditions (Experiment 2). Importantly, the greatest cost in search performance from a lack of knowledge of the target was for the small and large targets. These data on the differential impact of using known versus unknown targets indicate that the asymmetrical search pattern for nonlinearly versus

Table 5
Mean RTs (in Milliseconds) on Consecutive Target-Present Trials in Experiment 2 According to Target Size and Whether the Target Remained the Same or Differed From Trial $n - 1$ to Trial n

	Size		
Trial $n - 1$ to Trial n	Small	Medium	Large
Same	894	893	899
Different	915	913	909

linearly separable targets is influenced by top-down knowledge. Top-down guidance of search is more effective with linearly separable than with nonlinearly separable targets and distractors.

An alternative account of the disruptive effect of singleton search on the linearly separable targets is as follows. In singleton search, performance may be strongly affected by carry-over effects across trials (Maljkovic & Nakyama, 1994; Müller, Heller, & Ziegler, 1995). This might reflect positive priming of the representations of prior targets or inhibitory priming of the representations of former distractors. Negative carry-over effects might penalize linearly separable targets by biasing detection against a stimulus even if it is segmented from distractors. To test this, we assessed RTs in Experiment 2 on consecutive trials with target-present responses, comparing performance when the target stayed the same with when it changed. Table 5 shows the summary data. For all targets (small, medium, and large) there was a small cost when the consecutive targets differed relative to when they remained the same (an effect on the order of 10–20 msec). However, an ANOVA with target size and same/different carry-over showed that this cost was not statistically significant [$F(1,11) = 0.51, p > .48$]. Certainly the size of these negative carry-over effects is not sufficient to account for the contrast in results between Experiment 1 and Experiment 2. Instead we suggest that there is top-down guidance of search for known targets, and this is based on an operator that can set a linear boundary between targets and distractors.

The notion of a top-down linear separator mechanism can be linked to the model of Duncan and Humphreys (1989) in which search performance is characterized by a competition between the display elements for selection. Duncan and Humphreys proposed that visual selection is based on the distribution of *attentional weight* across items in a display. Items with a strong attentional weight "win" the competition for selection with the other items present. Items that group together will share their attentional weight, decreasing the chances of any individual representations' being selected but enabling the group to be selected "as a whole." Top-down processes act via a template to bias this competition in favor of the target. The effectiveness of top-down processes then depends, at least in part, on whether attentional weights can be limited to the set of target or distractor items, respectively. For efficient selection, the differential selection weight allocated to the target and distractors should be high. Top-down allocation of attentional weight is dependent on the similarity between target and distractor items and on the similarity between distractors (see Duncan & Humphreys, 1989). The more similar distractors are to each other, the more top-down activation and/or inhibition can be applied across all distractors in a display. It may be that limitations on top-down selection differentially impact on search for linearly separable and nonseparable targets and distractors. Typically, target–distractor similarity is highest and distractor–distractor similarity lowest for nonlinearly separable stimuli with distractor similarity decreasing for linearly separable stimuli. Top-down activation and/or inhibition could thus facilitate search for linearly separable stimuli more than search when items are nonlinearly separable.

As we noted above, searches in Experiment 2 could be affected by distractor grouping or they could be serial but involve the setting of a target template as more distractors are sampled. However, if the latter held, we might not expect search for the large target to be so slow; present slopes for the large target increased by a factor of three from Experiment 1 to Experiment 2 and absent slopes by a factor of four. The data fit rather more easily with the notion that search is largely determined by grouping between stimuli, as in the model of Duncan and Humphreys (1989) described above. We suggest that this primarily determined search when the target was unknown. Participants grouped stimuli in a spatially parallel manner and responded to the presence of a minimal size group, the singleton target. The price of this, however, may be that detection is slow, since shallow attentional weights will be distributed across the stimuli. The second cost of responding to the presence of a minimal-size group may be slowed RTs to large targets. Grouping between the distractors may be stronger due to the greater proximity between the individual exemplars, giving an RT advantage to the small and medium targets.

A recent study by Bauer et al. (1996a) argues against search being merely due to target–distractor and distractor–distractor similarity. They attempted to dissociate similarity factors from the effects of linear separability. Distractor ratios were manipulated for nonlinearly separable items, comparing ratios with 75:25 and 50:50 distractors (e.g., 15 distractors of one color and 5 of another against 10 distractors each of the respective colors). It might be expected that the unequal ratio would make search easier, as distractor heterogeneity would decrease. Decreases in heterogeneity should facilitate grouping and segmentation of targets from distractors. However, no differences in search were found between the two different ratios. This finding supports an account based on a spatially linear mechanism, which holds that separability should be crucial irrespective of the ratio of each type of distractor. On the other hand, without any sort of established metric, it is difficult to know whether Bauer et al.'s (1996a) similarity manipulations were of sufficient magnitude to produce a change in top-down control of search. It is possible that the magnitude of the described variations in distractor–distractor similarity in relation to target–distractor similarity were not enough to affect search performance. As noted above, the effect of nonlinear separability is evident for distractor differences only within 10 jnds of a target. It is logical then that given a particular value of target–distractor similarity, manipulations of distractor–distractor similarity have to be sufficiently large to affect search performance. This argument has some support from Experiment 3 in Bauer et al. (1998) in which target–distractor similarity was manipulated while distractor–distractor similarity was held constant. The target feature value was now more similar to one of the distractors given the 3:1 ratio within the total distractor–distractor similarity space. In contrast, in their Experiment 2, Bauer et al. (1998) found that manipulation of distractor ratios (with the same distractor feature values as in Experiment 3) had no effect on search performance. The manipulation of distractor–distractor similarity however was approximately a third of that of target–distractor similarity in Experiment 3 (as calculated for 16 distractors defined in CIE(x, y) color space using the heterogeneity metric in Bauer et al., 1996a). Although, there is no systematic quantification of the relations between target–distractor and distractor–distractor similarity, the relative manipulations might need to be closer than a factor of three. This proposal requires further empirical tests—for example, using stimuli coded in other feature dimensions.

In conclusion, the present results indicate the importance of top-down processes in search for linearly separable targets. The data argues against a linear spatially parallel mechanism alone being important. We suggest instead that (1) the detection of linearly separable stimuli is facilitated by top-down knowledge, and (2) grouping based on interstimulus similarities can influence performance.

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