

A new look at novelty effects: Guiding search away from old distractors

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We examined whether search is guided to novel distractors. In Experiment 1, subjects searched for a target among one new and a variable number of old distractors. Search displays in Experiment 2 consisted of an equal number of new, old, and familiar distractors (the latter repeated occasionally). We found that eye movements were preferentially directed to a new distractor on target-absent trials and that subjects tended to immediately fixate a new distractor after leaving the target on target-present trials. In both cases, first fixations on old distractors were consistently less frequent than could be explained by chance. We interpret these patterns as evidence for *negative guidance*: Subjects learn the visual features associated with the set of old distractors and then guide their search away from these features, ultimately resulting in the preferential fixation of novel distractors.

Search is not typically random but, rather, is guided to objects by a host of low-level and high-level factors (for a recent review, see Chen & Zelinsky, 2006). Search guidance has been studied most extensively in the context of a pattern's similarity to a designated target; the more similar a pattern is to a target, the stronger the guidance to that pattern (see, e.g., Duncan & Humphreys, 1989; Wolfe, 1994; Wolfe, Cave, & Franzel, 1989; Zelinsky, 2008). This relationship is clearest in the case of target-present trials, as is evidenced by a high proportion of initial saccades made directly to a search target (e.g., Chen & Zelinsky, 2006). Such strong guidance is to be expected, since the search item bearing the greatest similarity to the target is, by definition, the target itself.

Guidance, however, is not limited to targets; distractors can also resemble the target, and, to the extent that they do, search theories grounded in target-distractor similarity predict guidance to these objects as well. This relationship has received extensive support from studies exploring both ends of the similarity continuum. When distractors have no features in common with the target, adding these distractors to a display has little or no effect on search efficiency (e.g., Treisman & Gelade, 1980). Conversely, search becomes less efficient as target-distractor similarity increases, presumably because these target-like distractors are competing more strongly with the actual target for attention (e.g., Duncan & Humphreys, 1989; Wolfe, 1994). More direct support for this relationship has come from studies of eye movements during search, which have shown that the likelihood of a distractor being fixated increases with the number of features that it shares with a target (D. E. Williams & Reingold, 2001; Zelinsky, 2008; Zelinsky & Sheinberg, 1997; see also L. G. Williams, 1966, for an early observation). In addition to generally

supporting the role of target-related guidance in search, such analyses of distractor fixations also enable one to identify the target features that are most important for guidance (e.g., Motter & Belky, 1998; Pomplun, 2006; Rutishauser & Koch, 2007; see also Tatler, Baddeley, & Gilchrist, 2005).

Properties of distractors can also help to guide search to a target, irrespective of the similarity between the target and the distractors. For example, Duncan and Humphreys (1989) found that searching for a target among heterogeneous distractors was less efficient than searching for a target among homogeneous distractors. They interpreted this difference in terms of distractor-distractor similarity; similar distractors can be perceptually grouped and rejected en masse. More recently, a similar beneficial effect of distractors was reported by Neider and Zelinsky (2008). Their subjects searched for a vehicle target hidden among tree distractors, which varied in number and density. Counterintuitively, they found that search efficiency improved as trees were added to the display, creating a reverse set-size effect. This facilitatory effect was attributed to distractor grouping. Adding distractors to the scene resulted in the trees becoming grouped, which in turn created open-field objects through which the subjects could easily search. This was confirmed through eye-movement analyses; the subjects tended to fixate individual trees when the set size was small, but fixated the open field regions between clumps of trees when the set size was large. Because the number of these emergent field regions was small relative to the number of trees, search efficiency improved, despite the addition of tree distractors and the overall increased visual clutter.

Yet another form of distractor-related guidance focuses on the role of global contextual influences in search. Chun

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and Jiang (1998) manipulated visual context in two conditions; the same configurations of search items were either repeated or different configurations were used on each trial. The researchers found that search was more efficient when configurations repeated, suggesting that the global configurations of distractors were learned and used to cue the locations of the target (but see Kunar, Flusberg, Horowitz, & Wolfe, 2007, for a failure to find search guidance under similar conditions). In a subsequent study, Chun and Jiang (1999) extended their evidence for contextual cuing to a nonspatial relationship between targets and distractors. Distractor configurations did not repeat; rather, the subjects had to search for a vertically symmetric target among randomly positioned distractors. In a consistent-mapping condition, particular targets were paired repeatedly with particular distractor sets. No association existed between targets and distractors in a variable-mapping condition. Search was more efficient under the consistent-mapping conditions, suggesting that subjects learned the association between a target and a distractor set and used this information to cue a specific target template. Taken together, the Chun and Jiang (1998, 1999) studies showed that visual contexts—specifically, the spatial layout of distractors and their associations to targets—can be learned implicitly and used to guide search.

More recent studies have been focused on the relationship between search guidance and the representation of items in working memory (WM). In most of this work, a dual WM/search task was used in which the contents of WM were related to either the search targets or the distractors. When the item held in WM matched the search target, search efficiency increased, suggesting better guidance toward the target (Soto, Heinke, Humphreys, & Blanco, 2005; Woodman & Luck, 2007). The evidence for distractor guidance from WM is more mixed. Some studies have shown that search efficiency is unaffected when the contents of WM match a distractor (Downing & Dodds, 2004; Houtkamp & Roelfsema, 2006). However, Woodman and Luck recently reported an increase in search efficiency with the number of distractors matching WM contents, a relationship that they attributed to the use of WM to reject patterns in the search display. At this time, what seems clear from these studies is that holding a pattern in WM does not automatically draw one's attention to that pattern during search, since this would have produced faster search times for targets but longer search times for distractors.

The relationship between object familiarity and search guidance has also been studied. One method of exploring this relationship has been to repeat target items on successive trials. A consistent finding from this work is that search efficiency increases with target repetition (see Kristjánsson, 2006, for a review). More pertinent to the present discussion, such repetition benefits have also been reported recently for distractors (Ariga & Kawahara, 2004; Geyer, Müller, & Krummenacher, 2006; Kristjánsson & Driver, 2008; Lleras, Kawahara, Wan, & Ariga, 2008). For example, Kristjánsson and Driver found faster search times when a given distractor type appeared on successive trials than when the distractors differed. They

attributed this repetition benefit to priming; when a distractor is repeated, the processing of that distractor on trial n primes processing on trial $n+1$, presumably giving the visual system a head start on the rejection of that distractor. Another line of research has addressed the relationship between object familiarity and search guidance by having subjects either search through sets of familiar or unfamiliar items (e.g., Malinowski & Hübner, 2001; Shen & Reingold, 2001) or acquire familiarity throughout a task by repeatedly searching through the same sets of targets or distractors (e.g., Mruczek & Sheinberg, 2005; Wolfe, Butcher, Lee, & Hyle, 2003; see also Schneider & Shiffrin, 1977, and Shiffrin & Schneider, 1977). Regardless of the method, better search efficiency was once again found when the distractors were familiar. However, the implication of these findings for search guidance is unclear. Is this improved efficiency due to preferential fixation of the target, as might be the case if familiar distractors were rejected as a group, or to factors less associated with guidance, such as the faster rejection of individual familiar distractors or the rejection of more distractors per fixation (i.e., a broader functional search window; see also Greene & Rayner, 2001, and Zelinsky & Sheinberg, 1995)? Answers to these questions remain open.

Of particular interest to the present study is whether the novelty of a single object affects search guidance. This question has been addressed most directly in the context of novel pop-out (Johnston, Hawley, Plewe, Elliott, & DeWitt, 1990). The subjects saw four briefly presented words, followed by masks, and were then shown another word and were asked to indicate where it had appeared in the initial display. Johnston et al. found that accuracy was best for novel words when the initial display contained one novel and three familiar words. Related novel pop-out effects have since been reported using visual search tasks (e.g., Gibbons, Rammsayer, & Lubow, 2001; Lubow & Kaplan, 1997). For example, Wang, Cavanagh, and Green (1994) found pop-out levels of efficiency when subjects searched for an unfamiliar target (a mirror-reversed N) among familiar distractors (normal Ns). However, other researchers have questioned the role of target familiarity in these studies, arguing that low-level feature differences between targets and distractors might have contributed to the reports of highly efficient searches; when these factors were controlled, search slopes were still shallow but not flat (e.g., Christie & Klein, 1995, 1996; Diliberto, Altarriba, & Neill, 2000).

To date, it is still unclear whether search is guided to a novel object, with some researchers supporting this relationship (e.g., Mruczek & Sheinberg, 2005; Wang et al., 1994) and others arguing against it (e.g., Malinowski & Hübner, 2001; Shen & Reingold, 2001). One potential reason for these discrepant findings is that all of the studies have focused on novelty-based guidance in the context of a search target, and targets are relatively unique objects in a search task. The features of real-world targets are presumably held in WM, resulting in the very efficient guidance often observed to these objects (e.g., Chen & Zelinsky, 2006; Zelinsky, 2008). Such strong feature-based target guidance, and variability in this guidance signal as-

sociated with the encoding and maintenance of features in WM, may obscure the more subtle guidance effects stemming from object novelty or familiarity. In some sense, the target may be the singularly *worst* object to use when asking whether object novelty attracts search. As for the recent reports of improved search efficiency for repeated distractors (e.g., Kristjánsson & Driver, 2008; Lleras et al., 2008), this pattern certainly suggests that search might be directed preferentially to novel objects, but it falls short of an actual demonstration of guidance.

EXPERIMENT 1

Determining whether search is actually guided to new objects is an important question, because it informs the nature of novelty and familiarity effects and, more broadly, of the search guidance process itself. In this study, we turned to distractor objects and an eye-movement analysis to clarify whether search is guided to a novel object. By focusing on distractors, we might observe novelty effects without the potential confounds introduced by target-related guidance. We manipulated distractor familiarity by having a set of distractors repeat from trial to trial but included on each trial a novel distractor that had not been previously presented. By characterizing guidance in terms of eye movements, we could directly observe whether a novel object is preferentially fixated. This enabled us to tease apart true guidance effects from postperceptual factors related to faster distractor rejection. Additionally, this study differs from previous novelty-based guidance studies in that we used visually complex objects, rather than letters or words, as stimuli. When compared with letters, random objects likely share relatively few visual properties that might mediate perceptual grouping. If novelty-based guidance requires such lower-level grouping, or if the target plays a special role in this variety of guidance (as would be the case if novelty was a feature that could be added to the target description), we should find little evidence for guidance in this study. However, if it is possible to learn the features of the familiar distractors and to collectively de-weight them in the guidance process, search might be guided *away* from these objects and, consequently, *toward* the novel distractor.¹

Method

Subjects. Twelve students from Stony Brook University participated in this experiment for course credit. All of them had normal or corrected-to-normal visual acuity and were naive with respect to the goal of the experiment.

Stimuli and Apparatus. The targets were 318 images of teddy bears obtained from Cockrill (2001) and modified for use in this experiment. Of these targets, 300 were used in the search task, and 18 were used in the practice trials; teddy bears were not repeated over trials. The distractors were 435 images of real-world objects randomly selected from the Hemera Photo Objects Collection (Gatineau, Quebec, Canada); 407 of these were used as distractors in the search task, and 28 were used in the practice trials. All of the images were resized to have the same bounding box area (8,000 pixels), where a bounding box was defined as the smallest rectangle enclosing an object. This normalization allowed object width to vary from 1.12° to 4.03° and object height to vary from 1.0° to 3.58°. Objects were positioned randomly in the display, with the constraint

that the minimum center-to-center distance between objects and the distance from center fixation to the nearest object was 180 pixels (about 4°). The viewing angle of the display was 26° horizontally and 20° vertically.

Stimuli were presented in color on a ViewSonic 19-in. flat-screen CRT monitor at a refresh rate of 100 Hz. A custom-made program written in Visual C/C++ (v. 6.0) and running under Microsoft Windows XP was used to control the stimulus presentation. Eye-movement and manual reaction time (RT) data were collected using the EyeLink II eyetracking system (SR Research, Ltd.). The spatial resolution of this video-based eyetracker was estimated to be 0.2°, and eye position was sampled at 500 Hz. Head position and viewing distance were fixed with a chinrest, and all responses were made with a game pad controller attached to the computer's USB port. Judgments were made with the left and right index-finger triggers; trials were initiated with a button operated by the right thumb.

Design. The 300 experimental trials were evenly divided into two target-presence conditions (present or absent) and three set-size conditions (2, 7, or 12); all manipulations were within subjects. We also manipulated distractor familiarity. On target-absent trials, one of the distractors was *new*, having never appeared in any of the previous trials. This means that a 12-item target-absent display consisted of 1 new distractor and 11 old distractors, and a 2-item target-absent display consisted of 1 new and 1 old distractor. Target-present displays were similarly composed, with 7-item and 12-item displays each having 1 target, 1 new distractor, and the rest old distractors. For 2-item displays, the distractor presented with the target was old on half of the trials and new on the other half of the trials.

For any given subject, a total of 11 objects were used as old distractors, meaning that these objects, or some subset thereof, appeared on every trial. All 11 objects were presented on 12-item target-absent trials; 10 of the 11 old distractors were randomly selected and presented on each of the 12-item target-present trials. For 7-item trials, 6 of the 11 old distractors were randomly selected and used in the target-absent displays; 5 of these 6 distractors were randomly selected and presented in each of the target-present trials. For 2-item target-absent trials, 1 of the 6 old distractors from the 7-item target-absent trials was selected and presented with a new distractor. This same old distractor was presented on half of the 2-item target-present trials.² Different 11-object sets of old distractors were used for each subject so that our results would not be overly dependent on a specific distractor set. Figure 1 shows a representative 12-item target-present trial.

Procedure. The task was to find a teddy bear among a variable number of random real-world objects. Following a nine-point calibration phase needed to map eye positions to screen locations, each



Figure 1. A representative target-absent trial from Experiment 1. The single new distractor was the truck (bottom left).

trial began with the subject looking at a central fixation target and pressing a button. In addition to starting the trial, this response was used to correct for drift in the eyetracker recording. A preview of the target teddy bear was then displayed centrally for 1 sec, followed by the search array. The subjects were asked to indicate, as quickly and as accurately as possible, whether this target was present or absent in the display by pressing the left or right triggers of the game pad. A tone provided accuracy feedback, and the search display remained visible for 1 sec following the buttonpress. This was done in order to determine where the subjects looked after making their search judgment. The entire experiment lasted approximately 1 h and was conducted in two blocks separated by a brief period of rest.

Results and Discussion

Manual data. The patterns of errors and manual RTs were unremarkable. Error rates averaged only 1.6%, with a false alarm rate of 0.5% and a miss rate of 1.1%. These error trials were excluded from all subsequent analyses. Figure 2 shows the mean RT data. The slope of the RT \times set size function was 11.9 msec/item in the target-present data and 34.3 msec/item in the target-absent data, yielding significant main effects of target presence [$F(1,11) = 10.33, p < .01$] and set size [$F(2,22) = 18.71, p < .001$], as well as a significant target presence \times set size interaction [$F(2,22) = 5.05, p < .05$]. These results indicate an effortful target-absent search but a relatively efficient target-present search. A shallow target-present slope is interesting in the present context, because it suggests that the insertion of a single novel distractor object into a display does not meaningfully compete with the strong guidance signal generated by a target.

Eye-movement data. Oculomotor measures of search have proven to be a highly sensitive means of observing guidance during the ongoing search task and have become an important supplement to manual search measures (Chen & Zelinsky, 2006; Motter & Belky, 1998; Zelinsky, 1996; Zelinsky, Rao, Hayhoe, & Ballard, 1997; Zelinsky & Sheinberg, 1997). To determine whether search was preferentially guided to the new distractor in each of our

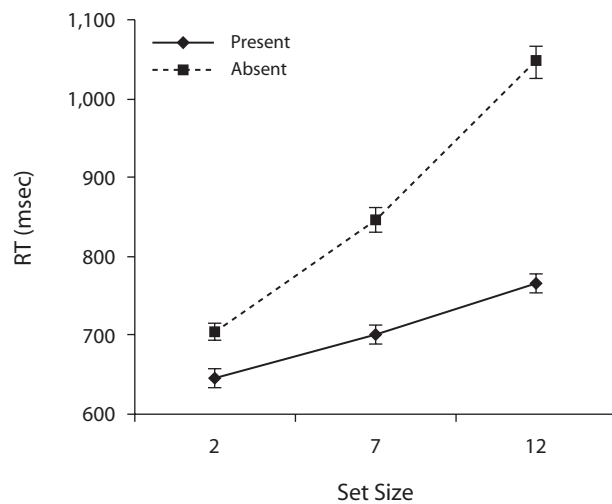


Figure 2. Average reaction times (RTs) for correct Experiment 1 trials, grouped by target-presence and set-size conditions. Error bars indicate one standard error of the mean.

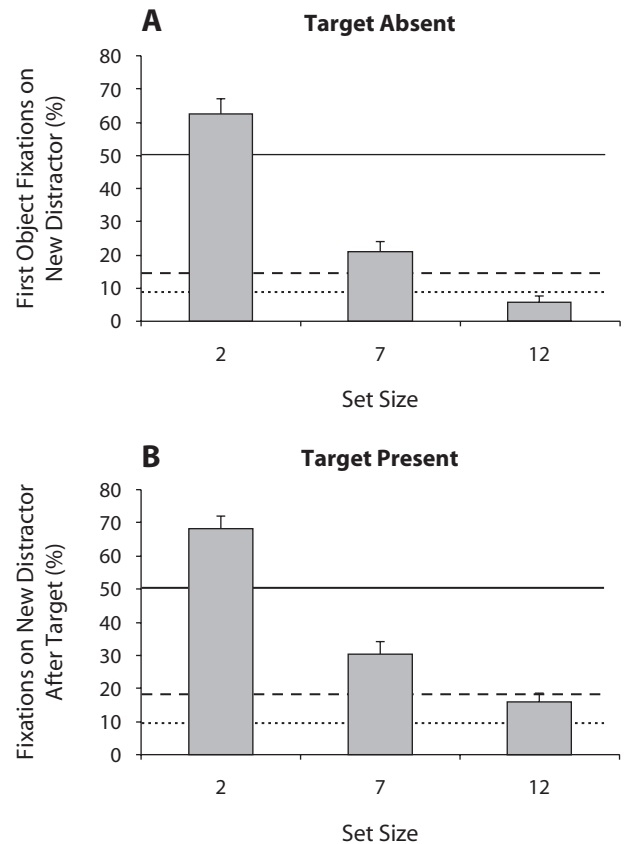


Figure 3. The percentage of target-absent trials in which the first object fixated was a new distractor (A), and the percentage of target-present trials in which the first object fixated after the target was a new distractor (B). The solid, dashed, and dotted lines represent chance baselines for the 2, 7, and 12 set-size conditions, respectively. Error bars indicate one standard error of the mean.

target-absent displays, we compared the percentage of trials in which this distractor was the first object fixated with baselines specific for each set-size condition (Figure 3A). Our baselines assumed the random selection of an object for initial inspection and produced rates of 50%, 14.3%, and 8.3% for set sizes of 2, 7, and 12, respectively. For set sizes of 2 and 7, we found that our subjects made their first object fixations on the new distractors at significantly higher rates than would be expected by chance ($t_s \geq 2.35, p_s < .05$). This trend did not hold for the set-size-12 condition, in which we in fact found a small but significant fixation rate for new distractors below the random baseline ($t = -2.29, p < .05$).

In the case of the target-present data, the target was fixated directly on 76%, 53%, and 50% of the trials in the 2, 7, and 12 set-size conditions, leaving too few cases of immediate new distractor fixations for analysis (an average of 10.4%). However, a novelty of our paradigm is that the search display remained visible for 1 sec after the search judgment, enabling us to compare the percentage of trials in which the subjects fixated a new distractor immediately after leaving the target with random baselines. These baselines were 16.7% and 9.1% for set sizes 7 and 12,

respectively, based on the assumption of an initial target fixation followed by a second fixation to a random distractor. A baseline of 50% was used for the 2-item condition, reflecting the fact that a new distractor appeared with the target on only half of the trials.³ Our treatment of the behavioral data reflected these baseline assumptions; we only analyzed cases in which the target was fixated first and a distractor was fixated after the target. Figure 3B shows a clear preference among subjects to look at the new distractor following their search judgment, with the percentage of new distractor fixations being above baseline for all three of the set-size conditions ($t_s \geq 3.09$, $p_s \leq .05$). In the case of the 7-item and 12-item displays, this result suggests an effect of novelty-based distractor guidance on search. Similarly, of those 2-item trials in which the subjects looked to a distractor after leaving the target, 68% were to the new distractor, again suggesting an effect of distractor novelty.

Can these data be explained without appeal to a guidance process? One possibility is that search is not guided to the novel object in our target-absent displays, but rather that all objects are sampled more or less randomly by a covert attention process. However, when attention alights on a novel distractor, this object is deemed interesting and is selected for acquisition by gaze. Novel distractors might therefore be preferentially fixated, relative to old distractors, without the benefit of a novelty-based guidance signal.⁴ To test this possibility, we analyzed the latency of the initial saccades to new and old objects. To the extent that this no-guidance hypothesis is true, one would expect shorter latencies to novel distractors, since an eye movement would be programmed to one of these objects as soon as it is sampled by attention. Moreover, this latency difference should be largest in the 2-item condition and smallest in the 12-item condition, because the number of random attention samples needed to locate the novel distractor would increase with the number of objects in the display. Table 1 shows the results of this analysis. Contrary to the predictions of the no-guidance hypothesis, initial saccade latencies to novel distractors were not significantly shorter than those to old distractors [$F(1,11) = 0.07$, n.s.]. And although we did find an increase in latency with set size [$F(2,22) = 6.92$, $p < .01$] (see also Zelinsky & Sheinberg, 1997) and an interaction between set size and novelty [$F(2,22) = 4.00$, $p < .05$], the direction of this interaction was opposite to that of the prediction: The latency difference between novel and old distractors *increased* with set size, with latencies to novel

distractors being *longer* than those to old distractors in the 12-item condition, not shorter. We can therefore reject the no-guidance hypothesis as a plausible explanation for the preferential fixation of novel distractors in Experiment 1.

Having dispatched this alternative explanation, we conclude that search is indeed guided to a novel object. This was evidenced by a bias to fixate new distractors on target-absent trials and by a tendency to look at new distractors after leaving the target on target-present trials. However, this novelty-based guidance depended on set size; guidance to novel distractors decreased with increasing set size, so much so that these distractors were not fixated more than was the baseline in the 12-item target-absent data. In Experiment 2, we more fully explored novelty-based distractor guidance in the context of a relatively large set size.

EXPERIMENT 2

There are at least two plausible explanations for the inverse relationship between distractor guidance and set size observed in Experiment 1. One straightforward explanation is that there is a limit on the number of objects that can be preattentively segregated as old or new, and that 12-item displays exceed this limit. An alternative explanation appeals to a proximity bias in search (e.g., Findlay, Brown, & Gilchrist, 2001). Given that objects were placed pseudorandomly in each display, old distractors were more likely to appear closer to starting fixation than the single new distractor, because of their overall greater number. A subject desiring to shift gaze to the new distractor might therefore have stopped to look at a closer old distractor simply because it was "on the way," a behavior that would compromise our measure of guidance. In Experiment 2, we addressed both of these possibilities.

As in the large set-size condition from the previous experiment, in Experiment 2, we used relatively dense 12-object displays. If the number of objects in the display prevented efficient novelty-based segregation, guidance in this experiment should also be poor. Recall also that in Experiment 1, subsets of distractors repeated at each successively smaller set-size condition, resulting in different degrees of oldness among the old distractors. This was done in order to avoid using different sets of old distractors for each set-size condition, which would have undermined our definition of *old* by limiting the presentation of these objects to only one third of the trials. By using only 12-item displays, we could look for limitations on distractor guidance, while removing this confound between variable set size and object familiarity.

To control for proximity biases, object placement in Experiment 2 was constrained to four concentric circles, with new and old distractors now appearing at each eccentricity with equal probability. In addition to thwarting contributions from proximity biases, this design builds on the previous work by introducing into each display multiple new distractors, one at each of the four eccentricities. The ratio of new to old distractors in a display may be a critical factor in determining novelty-based guidance. For example, Johnston et al. (1990) found novel pop-out only when

Table 1
Mean Initial Saccade Latency (in Milliseconds) to New and Old Distractors in the Experiment 1 Target-Absent Condition, Grouped by Set Size

Distractor Type	Set Size					
	2		7		12	
	<i>M</i>	<i>SEM</i>	<i>M</i>	<i>SEM</i>	<i>M</i>	<i>SEM</i>
New	169	5	179	6	214	16
Old	178	7	185	7	193	7

Note—*SEM*, standard error of the mean.

a single new item appeared among three familiar items; when there were two familiar and two unfamiliar items, localization accuracy did not differ between the old and new groups. In Experiment 2, three types of distractors appeared in each display: old distractors; new distractors; and a third, intermediate group consisting of distractors that repeated throughout the experiment but not on every trial. The latter group was added to explore the general cohesiveness of object segregation by familiarity: Do objects have to be entirely novel in order to attract search? To the extent that search can be guided to groups of novel objects in relatively large set-size displays, we expected to find a higher percentage of initial looks to new distractors than to the more familiar groups.

Method

Subjects. Fourteen students from Stony Brook University participated in this experiment for course credit. All of them had normal or corrected-to-normal visual acuity, and none had participated in Experiment 1.

Stimuli and Apparatus. Methodological details were identical to those in Experiment 1, with the following exceptions. The targets were 258 images of teddy bears randomly chosen from the 318 images used in Experiment 1; 240 bears were used as targets in the search task, and 18 bears were used as targets in the practice trials. As in Experiment 1, a different target teddy bear was used on every trial. The distractors were 1,093 images of common objects selected from the Hemera Photo Objects Collection. All of the images were resized in the same manner as those in Experiment 1.

Design. To control for initial eccentricity, objects were constrained to four circles, the radii of which were 4° , 6.5° , 8.9° , and 11.4° relative to the center of the screen. Six allowable object positions were defined on each circle, resulting in 24 possible object locations and a minimum center-to-center distance between objects of 3.4° . Twelve-object search displays were created by selecting locations from this 24-location array. This selection of object locations was further constrained by our distractor manipulation. Three types of distractors appeared in each search display: new, familiar, and old. On target-absent trials, 4 of the 12 distractors were *new*, meaning that they did not appear in any of the previous trials, and another 4 distractors were *old*, meaning that they appeared on every trial. The remaining 4 distractors were *familiar*; each familiar distractor was presented 24 times throughout the experiment (a 10% repetition rate). We randomly selected three positions (from the allowable six positions) on each circle, and presented 1 object from each of the three distractor types at these locations. One new, 1 old, and 1 familiar distractor therefore appeared at each of the four eccentricities used in this experiment. As in Experiment 1, different old distractors were used for each subject, so that our results would not depend on a specific distractor set. There were 240 experimental trials, evenly divided into target-absent and target-present conditions. Target-present and target-absent displays were constructed similarly, with the exception that a target teddy bear was substituted for 1 of the distractors. Over the course of the trials, this substitution occurred equally often for each of the three distractor types, and targets appeared equally often at each of the four display eccentricities. Figure 4 shows an example of a target-present trial, with new, familiar, and old distractors indicated.

Results and Discussion

Manual data. Error rates were again low (1.8% overall), with a false alarm rate of 0.4% and a miss rate of 1.4%. These trials were excluded from all subsequent analyses. Manual RTs averaged 720 msec in the target-present data,

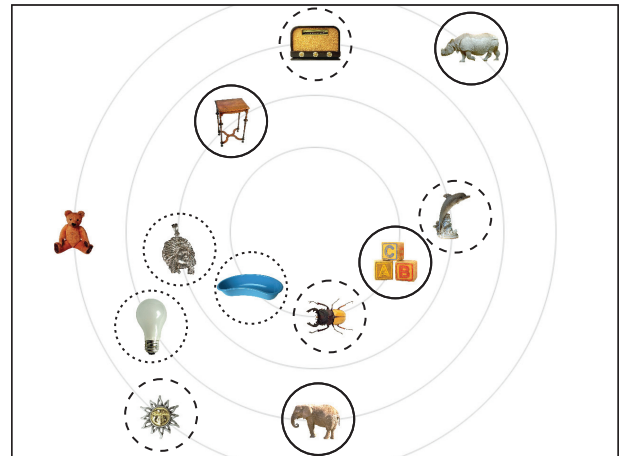


Figure 4. A representative target-present trial from Experiment 2. New distractors are indicated by solid circles, familiar distractors by dashed circles, and old distractors by dotted circles. The gray circles show the four object eccentricities. None of these circles were shown to subjects during the experiment.

significantly faster than the 890-msec RTs found in the target-absent condition [$F(1,13) = 51.94, p < .001$].

Eye-movement data. Our expectation was that search would be guided more efficiently to new distractors than to old ones and that familiar distractors would show an intermediate level of guidance. Our analysis of the target-absent search data provided partial support for this prediction. Figure 5A shows the percentage of first-fixated objects during target-absent search, grouped by distractor type. Given that old and familiar distractors are defined with respect to repeated presentations, all eye-movement analyses were confined to the last three quarters of the trials (180) to give subjects sufficient exposure to these objects. One-way ANOVAs indicated a significant main effect of distractor type on guidance [$F(2,26) = 3.87, p < .05$], which post hoc tests revealed to be due to fewer old distractors being fixated initially relative to new or familiar distractors ($p < .05$ for both comparisons); new and familiar distractors did not differ in terms of their initial fixation rates. These guidance effects, however, were small. Indeed, the fixation rates for new and familiar distractors did not reliably differ from the 33.3% rate expected by chance, although the fixation rate for old distractors was significantly lower than this random baseline [$t(13) = -2.35, p < .05$]. With respect to the target-absent data, it is therefore fairer to say that search was guided *away* from old distractors rather than *toward* new or familiar distractors—what we refer to as *negative guidance*.

As was the case in Experiment 1, a clearer pattern of guidance emerged in the target-present data. These data are shown in Figure 5B and reflect a significant main effect of distractor type [$F(2,26) = 24.50, p < .001$]. Following acquisition of the target, new distractors were more likely to be fixated than familiar distractors ($p < .01$), and familiar distractors were more likely to be fixated than old distractors ($p < .001$). A similar trend was found

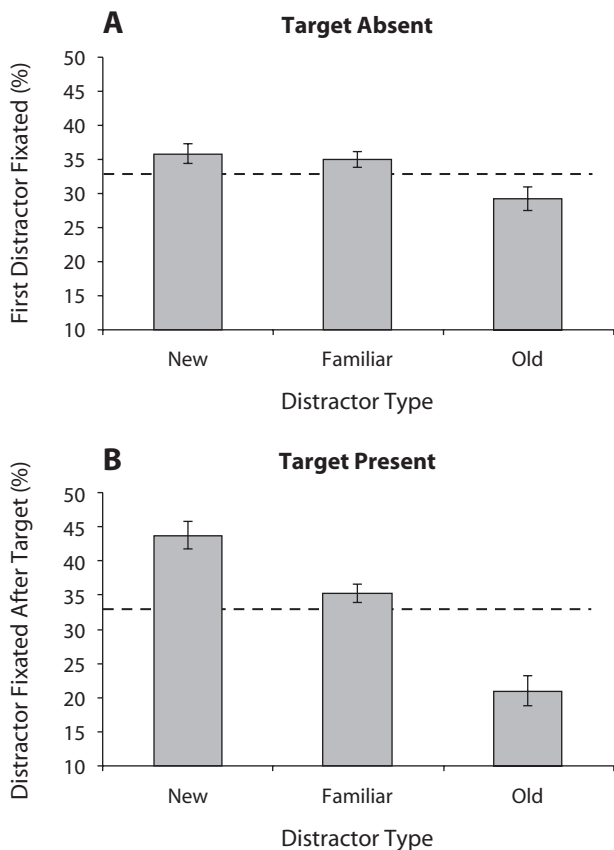


Figure 5. The percentage of first object fixations, grouped by distractor type, in target-absent (A) and target-present (B) trials from Experiment 2. Dashed lines indicate chance. Error bars indicate one standard error of the mean.

with respect to the random baseline. The rate of posttarget fixations on new distractors was significantly greater than chance [$t(13) = 5.12, p < .001$], and the corresponding rate of old distractor fixations was significantly less than chance [$t(13) = -5.69, p < .001$], patterns again indicating negative guidance. Initial posttarget fixations on familiar distractors were at chance in this task. In contrast to the target-absent data, these effects of novelty on distractor guidance were quite large: New and old distractors were fixated about 10% above and below baseline, respectively, and the rate of initial posttarget fixations to new distractors was nearly double that observed to old distractors.

In addition to guidance, other aspects of overt search behavior also varied with distractor type. Figure 6A shows the average numbers of fixations to the three distractor types in target-absent trials. New distractors were fixated more than familiar distractors, which were fixated more than old distractors [$F(2,26) = 24.96, p < .001$]. In Figure 6B, the average numbers of fixations are shown for target-present trials. Although the majority of fixations were made to the actual targets, new distractors again received more fixations than did familiar distractors, and these again received more fixations than did old distractors [$F(3,39) = 91.89, p < .001$]. Table 2 indicates that

this preference for novel distractors also extended to the durations in which objects were inspected. Average fixation durations for new and familiar distractors were significantly longer than for old distractors. This was true for both target-absent trials [$F(2,26) = 9.98, p < .01$] and target-present trials [$F(3,39) = 35.26, p < .001$]. Fixation durations on new and familiar distractors, however, did not differ. As for initial saccade latencies to distractors in target-absent trials, these fixation durations were 193, 199, and 195 msec for new, familiar, and old distractors, respectively. None of the differences between conditions were significant (all $ps > .1$). As in Experiment 1, the

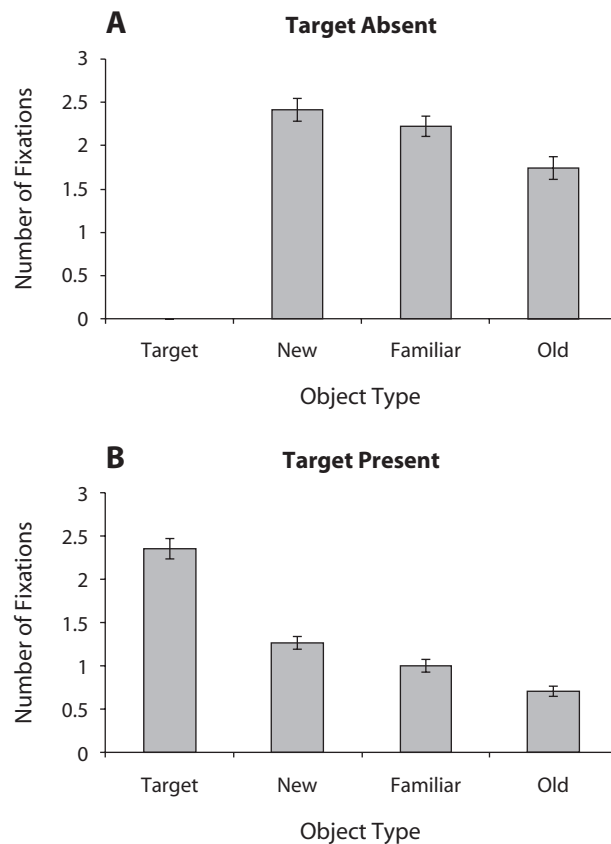


Figure 6. The average number of fixations on each type of search item in target-absent (A) and target-present (B) trials from Experiment 2. Error bars indicate one standard error of the mean.

Table 2
Mean Fixation Durations (in Milliseconds) in the Target-Absent and Target-Present Conditions From Experiment 2, Grouped by Object Type

Object Type	Target			
	Present		Absent	
	<i>M</i>	<i>SEM</i>	<i>M</i>	<i>SEM</i>
Target	414	28	—	—
New	236	10	235	6
Familiar	232	10	230	6
Old	213	9	216	8

Note—*SEM*, standard error of the mean.

failure to find shorter latencies to new distractors provides evidence against a no-guidance interpretation of the reported fixation preferences.

When eccentricity is controlled and subjects have an equal opportunity to fixate new and old distractors, we found clear evidence for novelty-based guidance, even in relatively dense 12-item displays. More fixations and longer duration fixations were also made on new distractors relative to old distractors, suggesting that more effort overall was devoted to inspecting these novel objects. Together, these findings suggest that novelty-based guidance *and* faster distractor rejection may have both contributed to previous reports of improved search efficiency with distractor familiarity.

However, there are two small inconsistencies in the Experiment 2 data. First, although the behavioral responses to familiar distractors were intermediate to those we found for new and old distractors in some measures (e.g., Figures 5B and 6), for other measures, the familiar distractors appear to have been treated as new (e.g., Figure 5A and Table 2). We attribute this inconsistency to the relatively low repetition rate used in our familiar distractor manipulation, which potentially made these distractors slightly more new than old. It will be interesting to explore distractor repetition more systematically in future work to better understand how distractor familiarity is acquired and used to negatively guide search (e.g., do distractors have to repeat over successive trials, or is general familiarity sufficient for guidance?). Second, our evidence for novelty-based guidance is stronger overall in the target-present data, a trend that we also observed in Experiment 1. We attribute this difference to the potential for competing guidance signals in our task and to the differential expression of this competition in target-present and target-absent trials.

The novelty-based guidance signal likely competes with many other primarily bottom-up (Itti & Koch, 2000) and top-down (Wolfe, 1994; Zelinsky, 2008) guidance signals, all vying for the control of search.⁵ A problem arises, however, in that these signals may pull search in different directions. The search target need not be the most salient object in a scene, and neither object might be the most novel. Given that gaze can shift in only one direction at a time, this creates competition. In the case of target-present trials, the target guidance signal would be very strong, easily overwhelming its competitors (Chen & Zelinsky, 2006; Zelinsky, Zhang, Yu, Chen, & Samaras, 2006). However, once the target is found, this guidance would suddenly stop, freeing the subjects to follow the novelty-based guidance signal. Search is also guided by the target on target-absent trials (Zelinsky, Zhang, & Samaras, 2008), but this guidance is likely to be weaker and to continue even after the response, as the subjects attempt to confirm their judgment. This continuous competition throughout a target-absent trial would tend to drive the fixation rate on novel distractors to near chance. We therefore speculate that, although many guidance signals may be in play during both target-present and target-absent search, the sudden release

from target guidance in target-present trials results in the greater expression of novelty effects in that condition.

GENERAL DISCUSSION

In this study, we asked how distractor novelty affects search guidance, and this effort produced several findings that build on previous work relating object familiarity to search. First, we found that novelty-based guidance extends to distractors; previous work had looked mainly at how object novelty affects the detection of targets. The negative guidance of search away from old objects appears to be a more general property of search, leading to the preferential fixation of novel targets and distractors alike. Indeed, such negative guidance may underlie a bias to look at new objects that extends well beyond search, as is evidenced by our subjects' choosing to fixate novel objects upon completion of their search task. Second, we quantified these effects using a variety of oculomotor measures, including the likelihood of an object being initially fixated, the number of fixations on a distractor, and the average duration of these fixations. In previous studies, novelty or familiarity effects were defined in terms of changes in manual search efficiency, leaving open the possibility that these effects might be the by-product of an efficient rejection of familiar distractors by postperceptual processes rather than of guidance. Although we did find some evidence for efficient distractor rejection, the totality of our findings cannot be easily explained without assuming actual guidance away from old distractors. Third, we showed that novelty-based guidance can be extended to groups of objects. It was unclear from previous work whether such guidance required that only a single novel object be presented with old objects, a constraint that would significantly diminish the importance of this form of guidance. Our work shows that novelty-based guidance is far more robust, suggesting that objects can be segregated very early during search on the basis of their familiarity.

These findings raise challenging questions for search theories. A cornerstone theoretical assumption is that search is guided to target-like patterns (Wolfe, 1994; Wolfe et al., 1989; Zelinsky, 2008). Although we certainly believe this to be true, our data suggest that such a strict focus on the target is overly narrow; search is also negatively guided to new distractors. How is such distractor guidance possible, and how must theories be modified to accommodate such guidance?

One explanation for novelty-based distractor guidance might appeal to the learning of distractor templates from previous exposures. Although search theories do not ordinarily assume the existence of such templates for distractors, they might presumably be matched to the distractors in a scene and used to guide search in much the same way as guidance from target templates. Consistent with this explanation is the suggestion of a long-term inhibition of return for previously viewed objects (Morgan, Paul, & Tipper, 2005; Tipper, Grison, & Kessler, 2003). According

to this theory, a blueprint for inhibitory processing can be stored and retrieved from memory along with the other properties of that object. Applied to the present context, old distractors might have elicited the reactivation of inhibitory processes used to reject those objects on previous trials. Assuming that this inhibition is tied to objects rather than to their locations, search might be guided away from old distractors, resulting in the bias toward new distractors observed in this study.

Rather than assuming that search is guided to new objects by being negatively guided *away* from old objects, an alternative explanation might be that novelty itself is represented and used to positively guide search. This, in a sense, treats novelty as a sort of feature, which can compete with other features extracted from bottom-up analyses of a search scene. If this feature could then be weighted in a computation of saliency, search might therefore be guided to novel objects much like it is guided to regions of high color or luminance contrast (e.g., Itti & Koch, 2000). Such a view is also broadly consistent with the biased competition model of attention (Desimone & Duncan, 1995). According to this model, objects are weighted on a variety of dimensions by bottom-up and top-down processes, with these objects competing with each other for selection in proportion to their activation. This competition can be biased by a variety of factors, one of which is believed to be object novelty. The suggestion is that the neural representations of novel objects are generally more active than those of familiar objects, resulting in these objects' being advantaged in the competition and consequently more likely to be selected for further processing.

Although the two previous explanations are appealing in some respects, neither offers a satisfying account of the novelty-based guidance effects reported in this study. The suggestion that long-term inhibitory processes can be associated with distractors presumes that these objects must be recognized at some level, so as to distinguish between those objects that should be inhibited and those that should not. However, search guidance has traditionally been thought to reflect the *selection* of an object for higher level processing, placing it before recognition, not after (Wolfe, 1994). If an object has already been recognized as a distractor, new or old, why would there be guidance to that object at all? If distractor guidance is ultimately shown to use such inhibitory templates, a major reconceptualization of search theory would clearly be required.

As for the suggestion that object novelty is a basic feature that can be used to guide search, this seems more a restatement of the phenomenon than a principled theoretical explanation. If novelty is a feature, how is it derived? The mechanisms underlying color and orientation features are relatively clear and grounded in neurophysiology (e.g., Zeki, 1978). There is no comparatively clear mechanism—neural or otherwise—for how to compute a novelty feature (although see Itti & Baldi, 2006, for a type of novelty feature defined for motion sequences). The fundamental problem is that novel objects comprise an

open set, making it computationally problematic to learn features or form templates for these objects without exploiting information from familiar objects, a closed set. To the extent that the novelty-based guidance effects reported here used features, it is therefore difficult to imagine how this process could be anything other than guidance *away* from the old distractors.

In our explanation for the present data, we assume negative guidance but not the existence of individual templates for old distractors. Rather, we treat the problem of novelty-based guidance as a form of categorical search. People are able to search very efficiently for categorically defined targets (e.g., Yang & Zelinsky, 2006), and it may be the case that the subjects in our task were treating the old distractors as a group and negatively guiding their search away from this category of objects. Although previous studies have addressed the topic of categorical guidance (e.g., Levin, Takarae, Miner, & Keil, 2001; Wolfe, Horowitz, Kenner, Hyle, & Vasani, 2004), theories for this variety of search are still in their infancy. One promising approach is to use machine-learning techniques to obtain the discriminative features for an object category, and then to use these features to guide search rather than the features specific to a given target object (Zhang, Yang, Samarasinghe, & Zelinsky, 2006). Extending this idea to the present context, we speculate that our subjects learned the visual features that are most descriptive of the set of old objects. However, rather than guiding search to these objects, these features were de-weighted in the guidance operation, with the net effect of this de-weighting being the preferential fixation of new objects in the display (for a related suggestion, see Bundesen, 1990).

The process described above can account for all of the findings reported in this study. Not only does it explain the guidance observed to new distractors, it also explains why old distractors were fixated at a below-chance rate even in the absence of positive guidance (Figure 5A) and why this negative guidance effect appears to be the more robust of the two. This explanation also accounts for why familiar distractors showed an intermediate level of negative guidance; these objects were less likely to contribute to the set of features defining the category of old objects. Finally, this account also predicts a drop-off in novelty-based guidance with an increase in set size, as was observed in Experiment 1. This is because the feature heterogeneity of a set of real-world objects will likely increase with the number of objects in the set, and a more heterogeneous set of old objects will lead to greater feature overlap with new distractors, thereby diminishing guidance. Future work will attempt to critically test this categorical guidance hypothesis by using new distractors that share features with the class of the old distractors (e.g., colors, shapes, or perhaps even parts). If our interpretation is correct, feature overlap between the new and old distractors should prevent search from being guided to the new objects, suggesting that novelty-based guidance is actually driven by categorically defined features, and not novelty per se.

AUTHOR NOTE

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NOTES

1. In this study, we draw an operational equivalency between guidance to novel objects and guidance away from familiar objects, because any evidence for one would also be evidence for the other. However, conceptually, these processes are quite different. We will more fully explore the theoretical importance of this distinction in the General Discussion.
2. The use of a constant set of repeating distractors in the context of a set-size manipulation means that some old distractors will be older than others because of their greater repetition at each successively smaller set size. In the present experiment, the most repeated items were therefore those old distractors used in the two-item conditions.
3. Probabilistic estimates of guidance become meaningless when the item of interest is the only other object in the display, making this baseline qualitatively different from the other two. Rather than indicating guidance, an above-baseline fixation rate in this case would indicate a greater tendency to look at the single remaining distractor when this distractor was new relative to when it was old.
4. We thank Jeremy Wolfe for suggesting this alternative explanation.
5. It is not yet known whether novelty-based guidance is best characterized as bottom-up, as was implied by our description of a negative guidance signal, or top-down, as would be the case if subjects were deliberately looking for a novel object. Making this distinction is difficult, since any top-down novelty bias must ultimately use low-level information, and any low-level novelty signal might give rise to a top-down strategy to search for new things.

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