Distractor familiarity leads to more efficient visual search for complex stimuli

RYAN E. B. MRUCZEK and DAVID L. SHEINBERG
Brown University, Providence, Rhode Island

Previous reports suggest that distractor familiarity plays an important role in determining visual search efficiency. However, the specific tasks used in those studies limit the extension of their findings to real-world situations and everyday images. In the present study, subjects engaged in a prolonged period of search experience as a control of their level of familiarity with a large set of target and distractor images. Reaction times and search slopes decreased dramatically over this period, especially for trials with a large target eccentricity and many distractors. Following extended practice, search among familiar distractors was more efficient than search among unfamiliar distractors. Furthermore, we found that familiar targets were located more efficiently than unfamiliar targets and that subjects were faster at locating targets that they had experienced in the majority of the search trials. These results show that prolonged visual experience facilitates processing of both target and distractor items during search.

Efficient search is central to real-world vision. Animals in the wild, for example, must constantly be on the lookout for potential predators, which appear in many different forms and contexts. Prior experience can play an important role in this search process. Some targets, for example, may appear more frequently than others, and search strategies can be adjusted to match these probabilities. At the same time, the surrounding environment may contain regularities that can be incorporated into search heuristics. Finally, the act of search itself may become more refined with experience. In other words, search efficiency can be enhanced by knowing what to look for, what not to look for, and how to look.

It is known that visual search efficiency in laboratory settings is determined by certain properties of the image array used. For example, if a search target contains particular physical attributes that are absent in the set of distractors, such as a “Q” among “O”s, search is highly efficient (Treisman & Souther, 1985). Such highly efficient search conditions are commonly referred to as *pop-out* conditions because the target is located rapidly, at a rate nearly independent of the number of distractors in the search array. Other aspects of the visual display are known to make search less efficient. For example, heterogeneity of the distractor set generally increases search times (Duncan & Humphreys, 1989).

This article is concerned primarily with the effect of image familiarity on visual search. Frith (1974) first noted

that the level of familiarity with target and distractors influences search efficiency. She found that it is more difficult to visually scan for letters among their mirror images than vice versa. Similarly, Reicher, Snyder, and Richards (1976) reported that search among familiar distractors was more efficient than search among unfamiliar ones. They attributed this difference to the segmentation stage of search rather than to poor classification of unfamiliar distractors (Richards & Reicher, 1978).

More recently, Wang, Cavanagh, and Green (1994) observed pop-out search conditions (search slope < 8 msec/item, by their definition) when unfamiliar targets were searched among familiar distractors, but not when other target-distractor combinations were used. In other words, highly efficient search required a familiarity difference between targets and distractors, with the distractors being familiar. Wang et al. concluded that familiar items are processed rapidly and easily but unfamiliar ones require more attention. An alternative interpretation is that familiarity serves as a primitive feature whereas novelty represents a departure from that standard (Treisman & Souther, 1985). In either case, novel items can pop out of a familiar background.

Using stimulus sets with feature difference controlled between targets and distractors, Malinowski and Hübner (2001) and Shen and Reingold (2001) demonstrated that what is necessary for efficient search is familiarity with the distractors, not a familiarity difference between targets and distractors. One interpretation of their data is that familiarity enhances the ability to group distractors (Karni & Sagi, 1991; Malinowski & Hübner, 2001), which can then all be dismissed together (Duncan & Humphreys, 1989; Treisman, 1982).

Although many previous studies have exploited differences in search efficiency in various situations as a para-

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digm for identifying basic features (i.e., those visual features identified preattentively and across the entire visual field in parallel), none has directly explored the effects of familiarity as it develops over the course of an experiment or the extent to which the properties of visual stimuli can influence search efficiency in more natural contexts. The present set of experiments was thus designed to determine if familiarity with distractors, gained through prolonged search experience, leads to more efficient search times when complex visual stimuli and heterogeneous distractor sets are used. We also explored how visual search efficiency is affected by target familiarity and target experience.

In some ways, the specific task used here differs significantly from those used in previous studies. First, familiarity was controlled by allowing the subjects to engage in an extended period of search experience rather than by selecting stimuli or subject groups on the basis of inferred experience. In previous studies, target–distractor pairs consisted of a stimulus—typically a letter or number—and its mirror reflection, so that the targets and the distractors were composed of similar features. In these paradigms, one stimulus is designated as the target for a block of trials and the other is designated as the distractor. Thus, there is a severe constraint on the distractor conditions within which a particular target can appear. To compare across distractor or target images from different stimulus pairs, individual exemplars are assumed to be of equal familiarity. In our design, each target is searched among multiple sets of distractors, each with its own level of experience-based familiarity, and target–distractor combinations were not selected on the basis of shared image features between the targets and the distractors.

Shen and Reingold (2001) demonstrated that the magnitude of the familiarity effect for distractors is increased by the presence of low-level feature differences between target and distractor images. In the present study, the stimulus set was composed of complex images and heterogeneous distractors. Although we did not directly control any particular parameters of our stimuli (e.g., luminance contrast, spatial frequency), the variability within and across image groups makes it difficult to select a target on the basis of any single feature. Furthermore, target images were randomized on a trial-by-trial basis, which limited the ability of subjects to form a mental template of the target (or a particular feature of that target) prior to the onset of the stimulus array. Previous studies employed a present/absent task with a single target image for a block of trials. This may allow for such templates, which could potentially lead to increased search efficiency just as shape priming improves search performance (Laarni & Nyman, 1997). Finally, target and distractor images were randomized across subjects so that any salient images would not be limited to one image group.

In our search task, there was no apparent structure to the placement of target and distractors, since images were positioned pseudorandomly within the display. However, it has been shown that target eccentricity has a significant effect on search performance (Carrasco, Evert, Chang, &

Katz, 1995) and interacts with the set size effect (Carrasco & Frieder, 1997; Wolfe, O'Neill, & Bennett, 1998). To explore the effects of eccentricity under different levels of image familiarity, we constrained target eccentricity to one of three different distances from a central point.

It should be noted that our aim was not to create parallel search conditions. Rather, we were interested in comparing the efficiency of visual search as a function of image familiarity and task experience. This is consistent with the idea of a continuum of search difficulty dependent on the qualities of the search array (Duncan & Humphreys, 1989; Nakayama, 1990; Treisman, 1993; Wolfe, 1998). We found three factors that significantly increased search efficiency: distractor familiarity, the context of previous target experience, and, to a lesser extent, target familiarity.

EXPERIMENT 1

Experiment 1 was designed to determine the impact of distractor familiarity on search efficiency. Subjects engaged in an extended period during which they searched for any one of many targets in the presence of a set of heterogeneous distractor images. It has been shown that measures of search efficiency, such as search slopes, are dynamic and can change with practice for difficult searches (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977; Sireteanu & Rettenbach, 1995, 2000). We reasoned that any experience-dependent changes in search efficiency might be related to familiarity with the particular search array images. If the effects of distractor familiarity extend to complex images and heterogeneous distractors, search times and search slopes should be larger when targets are located in the presence of unfamiliar distractor images. To test this, we compared reaction times (RTs) across different target–distractor group pairs using familiar and unfamiliar distractors.

Chun and Jiang (1999) reported that search can be facilitated through what they termed *contextual cuing*, in which the consistent pairing of a target with particular distractor images can result in shortened RTs. To distinguish between contextual cuing and familiarity, we included two groups of target images. One group was experienced in the context of distractors during an initial search phase. The second was viewed in isolation during the initial search phase and in the presence of distractors only in a final block of test trials. If distractor familiarity, and not the association of the target with a particular distractor context, is critical for enhanced search efficiency, then improvement should be apparent for both target groups.

Method

Subjects. Seven naive subjects (5 females and 2 males) were recruited from Brown University and the surrounding community. The subjects were paid \$8/h for their time. All of the subjects reported normal or corrected-to-normal vision.

Stimuli. The stimuli used in all of the experiments were chosen from the Hemera Photo Objects Premium Image Collection (Gatineau, Quebec, Canada). The stimulus sets were the same for Experiments 1 and 2 and were comprised of a total of 120 images. Example

Figure 1. Example displays used in all three experiments. Subjects were asked to fixate a central spot, which was removed before the image array appeared. After stimulus onset, the subjects were free to make eye movements. The task was to indicate by a buttonpress which of many potential targets was present. One target (in this example, the teapot) was present on every trial. Dashed circles indicate potential target eccentricities (3°, 6°, and 9°) and were not visible during the experiment. Distractors were presented randomly, without overlap, in a 12° radius from the central point. Individual stimuli covered approximately 2° × 2° of visual space and were rotated randomly between 0° and 360°. The actual display contained full-color stimuli.

stimuli are shown in Figure 1. Full-color images were selected in such a way that there was no obvious categorical relationship between any of the stimuli. Owing to the complexity of these objects, there was no direct control over the low-level feature differences across the stimulus set. However, each image was randomly assigned to the target or distractor group for each subject. Thus, particular images were used as both targets and distractors across the subject population. Stimuli covered approximately $2 \times 2^\circ$ of visual angle and were rotated at a random angle between 0° and 360° .

Procedure. The subjects were seated 65 cm from a computer screen that covered $17.4^\circ \times 13.2^\circ$ of visual angle and had a resolution of $1,280 \times 1,024$ pixels. Each trial was initiated with a tone and the onset of a fixation spot. After 450 msec, the fixation spot was removed and the stimulus display was presented after a 200-msec delay. The subjects were not required to maintain fixation during the search. A trial ended when the subject pressed one of two buttons or 20 sec had elapsed. Auditory feedback signaled correct and incorrect responses and was present in every trial throughout the experiment. There was a 1,250-msec intertrial delay with an extra 500-msec delay after incorrect trials.

Experiment 1 required seven sessions, each 1 h long, over the course of 2 to 4 weeks. The first 2 days were the target training phase and consisted of 10 target training blocks. During target training blocks, the subjects learned, by trial and error, to associate an arbitrarily assigned buttonpress response (left or right) with each of 20 target images randomly chosen from the set of 120 images. Over the course of target training, the subjects viewed each target 100 times.

The 4 days following target training constituted the distractor familiarization phase. For the first 2 of these days, the subjects received one target training block followed by nine search blocks. During search blocks, the subjects were presented with 1, 6, or 21 images randomly positioned (without overlap) within a radius of 12° from a central point (Figure 1). One target was present on every trial and was located at an eccentricity of 3°, 6°, or 9° (Figure 1, dashed circles). The subjects were instructed to find a target image

they had previously learned and to make the appropriate buttonpress response. Trials were presented in a random order so that the subjects could not predict which of the 20 targets would be present on a given trial. Because the target button assignments were evenly split between left and right, chance performance in this task was 50%.

The 20 targets were divided into two groups (isolated targets and searched targets) on the basis of the subject's experience with each target during the distractor familiarization phase (Table 1). Searched targets were presented among 0, 5, or 20 distractors. These distractors were randomly selected for each subject from a set of 20 images and formed the group of familiar distractors (Table 1). During the distractor familiarization phase, each isolated target was always shown alone in a random location (3° , 6° , or 9° from fixation). Note that the only difference between isolated targets and searched targets among zero distractors is that searched targets also appeared among distractors during other trials. Isolated targets never appeared among distractors during the distractor familiarization phase. Each search block consisted of 120 trials: 30 isolated target trials (10 images $\times$ 1 set size $\times$ 3 eccentricities) + 90 searched target trials (10 images $\times$ 3 set sizes $\times$ 1 distractor group $\times$ 3 eccentricities).

During the last 2 days of the distractor familiarization phase, five regular search blocks (as defined above) were interleaved with four enhanced search blocks. The enhanced search blocks consisted of 120 trials of searched targets among 20 distractor images ($10 \text{ targets} \times 1 \text{ set size} \times 1 \text{ distractor group} \times 3 \text{ eccentricities} \times 4 \text{ repetitions}$). Enhanced search blocks allowed the subjects to gain more exposure to the familiar distractor set in order to speed up distractor familiarization.

Over the distractor familiarization phase, searched targets were more likely than isolated targets to appear on a given trial. Specifically, 75% of search block trials and all enhanced search block trials included one of the searched targets. The primary objective of the distractor familiarization phase was to allow the subjects to gain familiarity with the familiar distractor set. Thus, we did not balance the number of trials containing searched and isolated targets because it would have greatly extended the distractor familiarization phase.

Table 1
Description of Image Groups

Group (<i>n</i> Images)	Description
Experiment 1	
Isolated targets (10)	Viewed in isolation during the distractor familiarization phase and among distractors during the test block
Searched targets (10)	Viewed among distractors during the distractor familiarization phase and the test block
Familiar distractors (20)	Introduced during the distractor familiarization phase as distractors for searched targets; used in the test block as distractors for both isolated and searched targets
Unfamiliar distractors (20)	Introduced during the test block as distractors for both isolated and searched targets
Experiment 2	
Targets A (10)	Searched among Distractors A during the distractor familiarization phase and among all distractor groups during the test block
Targets B (10)	Searched among Distractors B during the distractor familiarization phase and among all distractor groups during the test block
Distractors A (20)	Introduced during the distractor familiarization phase as distractors for Targets A; used in the test block as distractors for Targets A and B
Distractors B (20)	Introduced during the distractor familiarization phase as distractors for Targets B; used in the test block as distractors for Targets A and B
Consistent distractors (<i>n</i> is context dependent)	Distractors that maintained the target–distractor pairings used in the distractor familiarization phase during the test block (i.e., Target A–Distractor A and Target B–Distractor B)
Inconsistent distractors (<i>n</i> is context dependent)	Distractors that crossed the target–distractor pairings used in the distractor familiarization phase during the test block (i.e., Target A–Distractor B and Target B–Distractor A)
AB-mixed distractors (<i>n</i> is context dependent)	Set of distractors used in the test block for all targets, half chosen from Distractors A and half from Distractors B
Unfamiliar distractors (20)	Introduced during test block as distractors for both Targets A and B
Experiment 3	
Isolated targets (10)	Five exemplars from each of the two target image categories; viewed in isolation during the distractor familiarization phase and among distractors during the test block
Searched targets (10)	Five exemplars from each of the two target image categories; viewed in the context of distractors during the distractor familiarization phase and the test block
Unfamiliar targets (10)	Five exemplars from each of the two target image categories; introduced as target images in the context of distractors during the test block
Familiar distractors (20)	Five exemplars from each of the four nontarget image categories; introduced during the distractor familiarization phase as distractors for searched targets; used in test block as distractors for isolated, searched, and unfamiliar targets
Unfamiliar distractors (20)	Five exemplars from each of the four nontarget image categories; introduced during the test block as distractors for isolated, searched, and unfamiliar targets

Note—Image groups are named on the basis of the subject's experience with those images during the distractor familiarization phase of each experiment. The specific images assigned to each group differed across subjects. For Experiment 3, target and distractor categories were also randomized across subjects.

The 7th and final day was the day of the main test phase. The subjects first performed a target training block to reacquaint themselves with the 20 targets. They then performed one test block, during which the task instructions remained unchanged: to find a known target and press the corresponding button. The test block was similar to the search blocks but unique in two ways. First, a second set of 20 new (unfamiliar) distractors was added (Table 1). Second, both isolated targets and searched targets were viewed among 0, 5, or 20 distractors. (Note that the terms *searched* and *isolated* refer to the subject's experience with a target during the distractor familiarization phase; see Table 1.) The test block consisted of 360 trials (10 images $\times$ 2 target groups $\times$ 2 distractor groups $\times$ 3 set sizes $\times$ 3 eccentricities).

For reference, Table 2 shows the number and types of blocks run on each day of Experiment 1, organized by experimental phase.

Results and Discussion

Data from 2 subjects were not included in any of the following analyses because they did not complete the en-

tire experiment. Error rates were low (~1.5%) across all trials excluding those of the target training blocks. Error rates did not differ significantly across these blocks of trials and thus were not analyzed further. Only correct trials were used in the analysis of RTs presented below.

Target training phase. The subjects learned the appropriate buttonpress response for all 20 targets quickly (Figure 2, top). By the third target training block on the 1st day, error rates were below 5%. A one-way (block) repeated measures analysis of variance (ANOVA) showed that there was a significant decrease in mean RT across all target training blocks [$F(24,96) = 12.478, p < .001$]. This effect was mainly a result of the change over the first three blocks; a post hoc analysis showed that no significant improvement in RTs was made after the second training block (HSD; all $ps > .9$). By the end of the first 2 days of training, the mean RT across all subjects was 447 msec.

Table 2
Description of Blocks Run on Each Day of Experiment 1

Phase	Day(s)	Blocks (<i>n</i>)
Target training	1 and 2	Target training (10)
Distractor familiarization	3 and 4	Target training (1), search (9)
	5 and 6	Target training (1), search (5), enhanced search (4)
Main test	7	Target training (1), test (1)

Note—For Days 5 and 6, search blocks (SBs) and enhanced search blocks (ESBs) were interleaved (SB, ESB, SB, ESB, . . .).

Distractor familiarization phase. To analyze any effects of learning during the distractor familiarization phase, we looked at mean RTs for searched targets across each day of the search blocks (Figure 3). A three-way (day $\times$ set size $\times$ target eccentricity) repeated measures ANOVA showed main effects of set size [$F(2,8) = 238.32, p < .001$] and eccentricity [$F(2,8) = 110.35, p < .001$] driven by longer RTs for larger set sizes and larger eccentricities.

A significant interaction between set size and eccentricity [$F(4,16) = 54.677, p < .001$] indicates that search slopes were steeper for targets at larger eccentricities. A greater susceptibility to set size for larger eccentricities has been previously reported (Carrasco et al., 1995; Wolfe et al., 1998) and is likely due to the fact that, for targets at larger eccentricities, added distractors are more likely to reside between the initial fixation and the target. Since search in this task is likely to proceed from the center out, attention is drawn to more distractors when targets appear at large eccentricities (Wolfe et al., 1998).

The subjects performed the searches more quickly as the distractor familiarization phase progressed, as is indicated by a main effect of day [$F(3,12) = 101.57, p < .001$]. Furthermore, the majority of this improvement was apparent for trials with the most eccentric targets [eccentricity $\times$ day interaction; $F(6,24) = 2.6513, p < .05$] and the largest number of distractors [set size $\times$ day interaction; $F(6,24) = 90.976, p < .05$]. Pavlovskaya, Ring, Gros-

Figure 2. Mean reaction times (RTs) over target training blocks for Experiment 1 (top), Experiment 2 (middle), and Experiment 3 (bottom). Dashed vertical lines denote day breaks. For Experiments 1 and 2, the first 20 blocks comprise the target training phase (10 blocks/day) and the last 5 target training blocks were performed as the first block of the day for the 4-day distractor familiarization phase (gray area) and on the day of the test block. Training was faster and asymptotic RTs were shorter in Experiment 3 than in Experiments 1 and 2. For Experiment 3, target training was performed on only 1 day (10 blocks). The inset shows mean RTs for searched targets (S), isolated targets (I), and unfamiliar targets (U) over the final target training block on the main test day for Experiment 3 (Day 6). Over this block of trials, there was no significant difference in RT across target groups ($p = .54$).

Figure 3. Mean reaction times (RTs, top panels) for searched targets over the 4-day distractor familiarization phase of Experiment 1 for target eccentricities of 3° (left), 6° (center), and 9° (right). Day marks begin at Day 3 because the first 2 days of the experiment were devoted to target training. RTs are averaged across subjects and across all search blocks on a single day (9 blocks/day for the first 2 days and 5 blocks/day for the last 2 days). Bottom panels show search slopes across the same 4-day period. Performance improved most dramatically for the 20-distractor condition (triangles) and for the most eccentric targets (right panels).

wasser, Keren, and Hochstein (2001) reported a similar eccentricity $\times$ day interaction. Over two test sessions, they found the largest performance enhancements for peripheral stimuli. Figure 3 shows that RTs for targets at 3° leveled off prior to those for targets at 6°. RTs for targets at 9° did not appear to asymptote.

The set size $\times$ day interaction shows that search slopes decreased significantly over the distractor familiarization phase (Figure 3, bottom panels). Across all eccentricities, search slopes decreased dramatically, from 67.7 msec/item to 21.0 msec/item. The final value does not indicate that the subjects were performing a parallel search, since definitions of parallel search are usually within the range of 5–10 msec/item (Treisman & Souther, 1985; Wang et al., 1994). However, from the plots in Figure 3 it appears that search slopes did not reach an asymptotic level and may have continued to decrease, at least for more eccentric targets. Either way, the subjects were clearly more efficient at locating searched targets by the end of the distractor familiarization phase, and this allowed us to test the effects of distractor familiarity on performance.

To determine whether or not there were any differences between the two target groups, we compared RTs for isolated targets with RTs for searched targets with zero dis-

tractors. A three-way (day $\times$ target eccentricity $\times$ target group) repeated measures ANOVA showed that the subjects were significantly faster at identifying searched targets (521 msec) than isolated targets [538 msec; $F(1,4) = 41.945$, $p < .01$]. This relatively small advantage is likely due to the fact that searched targets were seen in 75% of the trials during search blocks and were the only targets to appear in enhanced search blocks. Thus, the subjects could have biased their search toward those targets that they were most likely to encounter: searched targets.

As was expected, eccentricity also had a significant effect on RT for zero-distractor trials [$F(2,8) = 45.922$, $p < .001$]. Identification of targets at 3° (509 msec) was 44 msec faster than that for targets at 9° (553 msec). This increase in RT is likely due to a combination of factors, including both longer duration saccades (about 13 msec; Carpenter, 1988) and lower visual acuity at higher eccentricities. Presumably, more presaccadic information can be extracted from stimuli at lower eccentricities and, thus, target processing can begin earlier for targets at 3°.

RTs for isolated and searched targets without distractors decreased slightly over the 4 days of the distractor familiarization phase. This effect was about 25 msec for both target groups, but it was only marginally significant

Figure 4. Mean reaction times derived from the test block of Experiment 1 as a function of set size. Search among familiar distractors (circles) was significantly faster than search among unfamiliar distractors (squares; $p < .01$), and searched targets (left) were found significantly more quickly than isolated targets (right; $p < .05$). Search slopes also differed significantly across target and distractor groups (both $ps < .01$).

[$F(3,12) = 2.96, p = .075$]. This indicates that RTs for searched targets decrease mainly for trials with distractors, as is suggested by the set size $\times$ day interaction noted above.

Overall, these results suggest that the subjects processed the images more efficiently by the end of the distractor familiarization phase. Increases in processing speed may be due to either faster serial processing of individual objects or an increase in the number of simultaneously processed objects.

Main test phase. A four-way (set size $\times$ target group $\times$ distractor group $\times$ target eccentricity) repeated measures ANOVA on RTs showed the expected main effects of set size [$F(2,8) = 58.629, p < .001$] and target eccentricity [$F(2,8) = 37.578, p < .001$] as well as an interaction between the two [$F(4,16) = 14.129, p < .001$]. As in the distractor familiarization phase, these effects indicate that search was slower in the presence of distractors and with increasing target eccentricity, and that the set size effect was larger for greater eccentricities.

The main effect of distractor group was significant [$F(1,4) = 22.325, p < .01$], since the subjects were faster at searching for targets among familiar distractors (900 msec) than among unfamiliar distractors (1,070 msec). The interaction between distractor group and set size was also significant [$F(2,8) = 11.790, p < .01$]. Search slopes for familiar distractors (44.6 msec/item) were significantly less steep than search slopes for unfamiliar distractors (60.6 msec/item; Figure 4). In other words, search slopes increased by 46% when targets appeared in the context of unfamiliar distractors.

During the test block, both isolated targets and searched targets were presented among 0, 5, or 20 distractors and these groups were directly compared across all factors. There was a significant difference in RTs between isolated targets and searched targets [$F(1,4) = 20.545, p < .05$]. The subjects were faster at locating searched

targets (781 msec) in comparison with isolated targets (1,189 msec). Furthermore, there was a significant interaction of target group and set size [$F(2,8) = 15.954, p < .01$]; search slopes were much less steep for searched targets (25.6 msec/item) than for isolated targets (75.6 msec/item; Figure 4). Although the subjects had extensive experience with both target sets, the context of that experience created a distinction between the two groups of targets. The most likely interpretation of this result stems from the fact that searched targets were seen in over 75% of the trials during the distractor familiarization phase. In fact, as was noted above, in the target-only trials searched targets were identified more quickly than isolated targets, possibly because the subjects weighted their search toward those targets that were more likely to appear.

Although the subjects showed a tendency to bias their searches toward searched targets, the effects of distractor familiarity were similar across target groups. It is clear from Figure 4 that search was more efficient in the context of familiar distractors than in that of unfamiliar distractors, for both isolated and searched targets. This indicates that the effect of distractor group cannot be accounted for by a paired association between searched targets and familiar distractors during the distractor familiarization phase, which would serve as a form of contextual cuing (Chun & Jiang, 1999). Rather, extensive experience with the familiar distractor set allowed the subjects to more easily locate all of the targets embedded among these distractors. Thus, distractor set familiarity enhances search efficiency in the context of complex images and inhomogeneous distractors.

EXPERIMENT 2

Experiment 1 showed that familiarity with a distractor set can increase search efficiency even for complex, heterogeneous image arrays. However, because there was

only one target–distractor set pairing during the distractor familiarization phase, it was not possible to determine the extent to which distractor familiarity itself or the paired association between target and distractor groups speeded visual search. To investigate this distinction, in Experiment 2 we used two separate target–distractor set pairings that were crossed after an initial search phase. If paired associations between target and distractor groups influenced search times, then search for a target should be slowed in the presence of a familiar distractor set with which it had never been paired.

A second goal of this experiment was to further examine the changes in search efficiency over the distractor familiarization phase. It is not clear from Figure 3 whether the subjects' performance was at ceiling in Experiment 1. Neither RTs nor search slopes appeared to reach an asymptotic level, especially for the largest target eccentricities and the largest numbers of distractors. To gain insight into the performance limits of our paradigm, the distractor familiarization phase of Experiment 2 was extended and more emphasis was placed on trials with 20 distractors.

Method

Subjects. Five naive subjects (3 females and 2 males) were recruited from Brown University and the surrounding community. The subjects were paid \$8/h for their time. All of the subjects reported normal or corrected-to-normal vision.

Stimuli. The same set of stimuli, display, and timing parameters that were used in Experiment 1 were used in Experiment 2. Each subject was assigned a random selection of target and distractor images so as to limit the effects of salient features for particular images.

Procedure. Eight sessions, each approximately 1 h long, were required over the course of 2–4 weeks. The first 2 days were for target training, which was carried out exactly as in Experiment 1.

The following 5 days constituted the distractor familiarization phase of the experiment. The subjects performed one target training block to remind them of the targets, followed by seven blocks of search trials. Individual trials were similar to those in Experiment 1. In this experiment, however, the 20 target images were randomly divided into two groups: Targets A and Targets B. On each trial, distractor images were chosen from one of two groups—Distractors A and Distractors B—each consisting of 20 different images. Throughout the distractor familiarization phase, when presented in the context of distractors, Targets A appeared with Distractors A and Targets B appeared with Distractors B (Table 1). In each session, the seven search blocks consisted of one search block (3 set sizes) followed by six enhanced search blocks (set size of 20 only). Each search block consisted of 180 trials (10 images $\times$ 2 target–distractor pairs $\times$ 3 set sizes $\times$ 3 eccentricities). Each enhanced search block, in which every trial included 20 distractors, consisted of 120 trials (10 images $\times$ 2 target–distractor pairs $\times$ 1 set size $\times$ 3 eccentricities $\times$ 2 repetitions).

The 8th day was the main test day. The subjects performed one target training block to reacquaint themselves with the targets and one search block for a final measure of their performance. Finally, the subjects performed one test block of trials. In the test block, the task remained the same: to find a known target and press the corresponding button. Unlike in the search block, however, a target from either the Targets A group or the Targets B group could appear among distractors chosen from the Distractors A group or the Distractors B group, or from among a new set of 20 unfamiliar distractors (Table 1). Furthermore, targets were searched among a set of AB-mixed distractors. On these trials, half of the distractors were chosen from Distractors A and half from Distractors B (Table 1). The test block consisted

of 720 trials (10 images $\times$ 8 target–distractor pairs $\times$ 3 set sizes $\times$ 3 eccentricities) and was completed in six sets of 120 trials.

As a reference, Table 3 shows the number and types of blocks run on each day of Experiment 2, organized by experimental phase.

Results and Discussion

Error rates were low ($\sim 3.1\%$) across all trials excluding the target training blocks. Error rates did not differ significantly across these blocks of trials and thus were not analyzed further. Only correct trials were used in the analysis of RTs presented below.

Target training phase. As was the case in Experiment 1, the subjects learned the appropriate buttonpress responses for all 20 targets quickly. By the second target training block on the 1st day, error rates were below 5%. A one-way (block) repeated measures ANOVA showed that there was a significant decrease in mean RT across all target training blocks [$F(25,100) = 15.769, p < .001$]. This effect was mainly a result of the change over the first two blocks of training (Figure 3, middle). Post hoc analysis showed that no significant improvement in RTs occurred after the second block of training (HSD; all $ps > .1$). By the end of the first 2 days of training, mean RT across all subjects was 465 msec.

Distractor familiarization phase. To analyze any effects of learning during the distractor familiarization phase, we looked at mean RTs across each day for the search blocks (Figure 5). In this analysis, we collapsed the data across target groups since these groups were randomly chosen and had no implications across subjects. As we expected, many results were similar to those of the searched targets in Experiment 1. A three-way (day $\times$ set size $\times$ target eccentricity) repeated measures ANOVA showed main effects of set size [$F(2,8) = 184.15, p < .001$] and eccentricity [$F(2,8) = 38.387, p < .001$] driven by longer RTs for larger set sizes and larger eccentricities. Search slopes were highest at the largest eccentricities, as is indicated by a significant interaction between set size and eccentricity [$F(4,16) = 16.865, p < .001$]. As in Experiment 1, search was not only slower for more eccentric targets but also more susceptible to slowing as distractors were added.

Over the course of the distractor familiarization phase, overall search times decreased, resulting in a significant main effect of day [$F(5,20) = 231.60, p < .001$]. Once again, the majority of this improvement was apparent for trials with the largest number of distractors [set size $\times$ day interaction; $F(10,40) = 207.91, p < .001$]. The set size $\times$ day interaction indicates that search slopes decreased

Table 3
Description of Blocks Run on Each Day of Experiment 2

Phase	Day(s)	Blocks (<i>n</i>)
Target training	1 and 2	Target training (10)
Distractor familiarization	3–7	Target training (1), search (1), enhanced search (6)
Main test	8	Target training (1), search (1), test (1)

Figure 5. Mean reaction times (RTs, top panels) for searched targets over the distractor familiarization phase of Experiment 2 for target eccentricities of 3° (left), 6° (center), and 9° (right). Day marks begin at Day 3 because the first 2 days of the experiment were devoted to target training. RTs are averaged across subjects. Only one search block was performed on each day. Day 3 represents the first block of search trials that each subject performed, which explains the very long RTs. Day 8 represents the test day. Bottom panels show search slopes across the same period. Performance improved most dramatically for the 20-distractor condition (triangles) and for the most eccentric targets (right panels).

significantly over the distractor familiarization phase (Figure 5, bottom panels). Average search slopes across all eccentricities decreased from 133.6 msec/item to 18.1 msec/item. Although this final slope value is slightly lower than that obtained in Experiment 1 (21 msec/item), search slopes were still not completely flat, despite the more intense search experience in Experiment 2.

The interaction between target eccentricity and day was only marginally significant [$F(10,40) = 1.9066, p = .073$]. However, because the 1st day of distractor familiarization included only one search block and this was the first block of search trials that the subjects experienced, RTs were exceptionally high (Figure 5, Day 3). We ran a similar analysis excluding RTs from the 1st day of distractor familiarization (Day 3) and found a highly significant interaction between target eccentricity and day [$F(8,32) = 4.6899, p < .001$]. As in Experiment 1, the majority of improvement was seen for trials with the largest target eccentricities.

Main test phase. Four distractor groups were defined on the basis of each subject's experience with consistent, inconsistent, AB-mixed, and unfamiliar distractors (Table 1). Consistent distractors included those pairings

that the subject had experienced during the distractor familiarization phase (Targets A–Distractors A and Targets B–Distractors B). Inconsistent distractors included Targets A searched among Distractors B and vice versa. For AB-mixed distractors, half of the distractors were chosen from Distractors A and half from Distractors B. A set of 20 new images formed the group of unfamiliar distractors.

A three-way (set size $\times$ distractor group $\times$ target eccentricity) repeated measures ANOVA on RT showed main effects of set size [$F(2,8) = 216.87, p < .0001$] and target eccentricity [$F(2,8) = 60.323, p < .001$] as well as an interaction between set size and target eccentricity [$F(4,16) = 51.796, p < .001$]. These effects replicate the results from Experiment 1. Search was slower in the presence of increased numbers of distractors and for targets at larger eccentricities, and the set size effect was exaggerated at larger eccentricities.

The main effect of distractor group was also significant [$F(3,12) = 14.542, p < .001$]. Post hoc analysis indicated that RTs for unfamiliar distractors (875 msec) were significantly longer than those for any other distractor group (consistent, 737 msec; inconsistent, 773 msec; AB-Mixed, 742 msec), also replicating the findings of

Figure 6. Mean reaction times (RTs) derived from the test block of Experiment 2 as a function of set size. Search was significantly slower ($p < .001$) and slopes were significantly steeper ($p < .01$) for unfamiliar distractors (triangles) in comparison with all other distractor groups. There were no significant differences in RT or slope between consistent, inconsistent, and AB-mixed distractors.

Experiment 1. Furthermore, there was a significant interaction of distractor group and set size [$F(2,8) = 15.954$, $p < .01$], indicating that slopes were steeper for search among unfamiliar distractors (39.1 msec/item) than for search among all other distractor groups (Figure 6). There were no significant differences between other distractor groups, although search among inconsistent distractors (25.6 msec/item) was slightly less efficient than search among consistent distractors (20.3 msec/item) and AB-mixed distractors (20.4 msec/item). This slight increase in search slope for inconsistent distractors is apparent only for the most eccentric targets, resulting in a significant three-way interaction between distractor group, set size, and target eccentricity [$F(12,48) = 2.0840$, $p < .05$]. Overall, the results of Experiment 2 indicate that the majority of the efficiency gained from distractor experience is due to familiarity with the distractors themselves, rather than to an association between a group of targets and a group of distractors.

EXPERIMENT 3

In Experiments 1 and 2, we investigated the effects of distractor familiarity on visual search. By design, in these experiments the subjects were overtrained on the target images. In Experiment 3, we investigated the extent to which familiarity with particular target images influences search efficiency.

Previous studies have concentrated on the contribution of distractor familiarity to search efficiency. However, present/absent tasks, wherein the target is specified ahead of time, are not well suited for assessing the effects of target familiarity because subjects can retain a template of

the target stimulus to be found. In Experiment 3, we asked subjects to learn an association between target categories and buttonpress responses. Thus, we could introduce unfamiliar target exemplars without overtraining and while maintaining uncertainty about target identity on any given trial. If familiarity with a target leads to enhanced search efficiency, RTs and search slopes should be lower for previously experienced targets relative to unfamiliar targets.

Identification of objects at a categorical level is performed faster than identification at an individual level (Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976). Thus, we would predict that the category-based search task should be easier than the individual-based search task in Experiments 1 and 2. Wolfe et al. (1998) suggested that eccentricity and set size effects should vary with task difficulty. Thus, we expected that any effects seen in Experiment 3 would be smaller than those seen in Experiments 1 and 2 because subjects could potentially guide their search using particular features that are common to objects within target categories.

Method

Subjects. Six naive subjects (4 females and 2 males) were recruited from Brown University and the surrounding community. The subjects were paid \$8/h for their time. All of the subjects reported normal or corrected-to-normal vision.

Stimuli. The display parameters were the same as those in Experiments 1 and 2. However, unlike in the previous experiments, stimuli were chosen from six categories: butterflies, stuffed bears, lamps, chairs, baskets, and trucks (Figure 7). A total of 15 images were selected for each category from the Hemera Photo-Objects Premium Image Collection (Gatineau, Quebec, Canada). As in the previous experiments, the stimuli covered $2^\circ \times 2^\circ$ of visual angle and were rotated at a random angle between 0° and 360° .

Procedure. Experiment 3 required six sessions, each lasting approximately 1 h, over the course of 2–3 weeks. For each subject, two of the six image categories were randomly selected as target categories. The other four categories of images were used as distractors. An example of the target and distractor images selected for 1 subject is shown in Figure 7. Target training was similar to that in Experiment 1, except that only 1 day of training was required and the subjects were informed that one category of images required a left buttonpress and the other a right buttonpress.

The four distractor familiarization phase sessions were exactly as in Experiment 1. The 20 targets were divided into two groups: isolated targets and searched targets (Table 1). Each group consisted of five exemplars from each of the two target categories. Searched targets were presented among 0, 5, or 20 familiar distractors, which consisted of five exemplars from each of the four nontarget image categories (Table 1). On trials with 5 distractors, distractors were randomly chosen from the set of 20 familiar distractors without regard to image category. During the distractor familiarization phase, each isolated target was viewed in isolation, although its position was random. The first 2 days of the distractor familiarization phase consisted of one target training block followed by nine search blocks. Search blocks consisted of 120 trials: 30 isolated target trials (10 images $\times$ 1 set size $\times$ 3 eccentricities) + 90 searched target trials (10 images $\times$ 3 set sizes $\times$ 1 distractor group $\times$ 3 eccentricities).

To allow the subjects to gain more experience with the familiar distractor set, the last 2 days of the distractor familiarization phase consisted of five regular search blocks (as defined above) interleaved with four enhanced search blocks. The enhanced search blocks consisted of 120 trials of searched targets among 20 distractor images

Figure 7. Example stimulus set for 1 subject in Experiment 3. (A) Two image categories were randomly selected for each subject as the target categories. Each target group (searched, isolated, and unfamiliar) consisted of 5 exemplars from each of the two target categories. (B) The remaining four image categories were used to create the distractor groups. Each of the distractor groups (familiar and unfamiliar) was composed of 5 exemplars from each of the four nontarget categories. The actual stimuli were full-color images.

(10 targets $\times$ 1 set size $\times$ 1 distractor group $\times$ 3 eccentricities $\times$ 4 repetitions).

The 6th day was the main test day. The subjects first performed a target training block to reacquaint themselves with the targets. However, this target training block contained 10 new targets, 5 from each of the two target categories. These 10 new targets formed the group of unfamiliar targets (Table 1). The subjects then performed one test block of trials in which their task remained the same: to find an image from one of the target categories and press the appropriate button. Targets from all three groups (searched targets, isolated targets, and unfamiliar targets) were all searched for among the familiar distractors and from among a set of unfamiliar distractors (Table 1). The latter set of distractors contained five novel exemplars from each of the four nontarget image categories. The test block contained 540 trials (10 exemplars $\times$ 3 target groups $\times$ 2 distractor groups $\times$ 3 set sizes $\times$ 3 eccentricities) and was completed in 5 sets of 108 trials.

As a reference, Table 4 shows the number and types of blocks run on each day of Experiment 3, organized by experimental phase.

Results and Discussion

Data from 1 subject were excluded from the following analyses because this subject's error rates exceeded 10% during the test block. For the remaining subjects, error rates were low ($\sim 3.5\%$) across all trials excluding the target training blocks. Error rates for the remaining 5 subjects did not differ significantly across these blocks of trials and thus were not analyzed further. Only correct trials were used in the analysis of RTs.

Initial training phase. The subjects learned the appropriate buttonpress responses for the initial 20 targets quickly. Error rates were at about 3% on the first block

of trials. A one-way (block) repeated measures ANOVA showed that there was a significant decrease in mean RT across all target training blocks [$F(13,52) = 2.7575, p < .01$]. However, mean RTs decreased only from 443 msec to 372 msec throughout the entire experiment (Figure 2, bottom). The shortened RTs in Experiment 3 are presumably due to the fact that the subjects had to identify targets only at a categorical level, not an individual level as in Experiments 1 and 2.

Distractor familiarization phase. For searched targets, a three-way (day $\times$ set size $\times$ target eccentricity) repeated measures ANOVA on mean RTs across day showed main effects of set size [$F(2,8) = 44.896, p < .001$] and eccentricity [$F(2,8) = 65.319, p < .001$]. These effects were driven by slower searches for larger set sizes and for targets appearing at larger eccentricities (Figure 8). Similar effects were also found in Experiment 1, but their

Table 4
Description of Blocks Run on Each Day of Experiment 3

Phase	Day(s)	Blocks (<i>n</i>)
Target training	1	Target training (10)
Distractor familiarization	2 and 3	Target training (1), search (9)
	4 and 5	Target training (1), search (5), enhanced search (4)
Main test	6	Target training (1), test (1)

Note—For Days 4 and 5, search blocks (SBs) and enhanced search blocks (ESBs) were interleaved (SB, ESB, SB, ESB, . . .). The target training block for Day 6 (main test phase) included the unfamiliar target group.

Figure 8. Mean reaction times (RTs, top panels) for searched targets over the 4-day distractor familiarization phase of Experiment 3 for target eccentricities of 3° (left), 6° (center), and 9° (right). Day marks begin at Day 2 because the first day of the experiment was devoted to target training. RTs are averaged across subjects and across all search blocks on a single day (9 blocks/day for the first 2 days and 5 blocks/day for the last 2 days). Bottom panels show search slopes across the same period. Performance improved most dramatically for the 20-distractor condition (triangles) and for the most eccentric targets (right panels).

magnitude was smaller in Experiment 3. For example, the slopes of the eccentricity effect were about 62 msec/deg and 38 msec/deg for Experiments 1 and 3, respectively. As stated above, this was expected, because less visual evidence must be accrued in the category-based search task than in the identity-based search task.

A significant interaction between set size and eccentricity [$F(4,16) = 33.378, p \ll .001$] indicates that search slopes were steeper for targets at larger eccentricities. As in Experiment 1, search was not only slower for more eccentric targets but also more susceptible to slowing as distractors were added.

A main effect of day [$F(3,12) = 15.029, p < .001$] suggests that the subjects performed the searches more quickly as the distractor familiarization phase progressed. The majority of this improvement was apparent for trials with the largest number of distractors [set size $\times$ day interaction; $F(6,24) = 24.370, p < .001$] and the most eccentric targets [eccentricity $\times$ day interaction; $F(6,24) = 9.5995, p < .001$]. The eccentricity $\times$ day interaction was due primarily to a lack of significant improvement for targets at 3° after the second day of search trials.

The set size $\times$ day interaction indicates that search slopes decreased significantly over the distractor familiarization phase (Figure 8, bottom panels). Across all eccentricities, search slopes decreased dramatically, from

39.2 msec/item to 13.6 msec/item. As in the previous experiments, by strict definition the subjects were not performing parallel searches, but they were clearly more efficient after the distractor familiarization phase. The final search slope (13.6 msec/item) was also less steep than the complementary search slopes of Experiment 1 (21 msec/item) and Experiment 2 (18.1 msec/item). Differences in the stimuli between experiments likely account for the observed difference. For example, in the category-based search task, targets likely shared some common features that the subjects may have exploited to guide search.

The three-way interaction between set size, target eccentricity, and day was significant [$F(12,48) = 3.5812, p < .001$]. This appears to be due to the minimal improvement in RTs over the distractor familiarization phase for targets at 3° eccentricity. The only significant change between consecutive days for 3° targets occurred over the first 2 days of search trials and was limited to the 20-distractor condition (HSD; $p < .001$). All other differences between consecutive days were insignificant. Once again, this effect is likely due to the fact that the category-based search task was easier than the identity-based search task.

To determine if there were any differences between the two target groups during the distractor familiarization phase, we compared RTs for isolated targets and for those searched target trials with zero distractors. A three-way

Figure 9. Mean reaction times derived from the test block of Experiment 3 as a function of set size. Searched targets (left) were found significantly more quickly than isolated targets (center) or unfamiliar targets (right; $p < .05$), and search among familiar distractors (circles) was significantly faster than search among unfamiliar distractors (squares; $p < .05$). Search slopes were also significantly different across target ($p < .01$) and distractor ($p < .05$) groups.

(day $\times$ target eccentricity $\times$ target group) repeated measures ANOVA showed that the subjects were significantly faster at identifying searched targets (454 msec) than isolated targets [471 msec; $F(1,4) = 8.3931$, $p < .05$]. As in Experiment 1, this difference is likely due to the fact that searched targets were seen in 75% of the trials during search blocks and were the only targets to appear in enhanced search blocks. Thus, it appears that the subjects weighted their search toward those targets that were most often encountered.

For zero-distractor trials, identification of targets at 3° (450 msec) was about 27 msec faster than identification of targets at 9° (478 msec), resulting in a main effect of target eccentricity on RT [$F(2,8) = 66.293$, $p < .001$]. This difference was smaller than that found for the analogous condition in Experiment 1 (44 msec). This is an indication that the magnitude of the eccentricity effect is greater when additional relevant visual information must be acquired *after* the saccade, which may not always have been necessary in the easier discrimination conditions of the present experiment.

RTs for isolated and searched targets without distractors did not change significantly over the 4 days of the distractor familiarization phase [$F(3,12) = 2.2537$, $p > .1$]. However, the subjects were slightly slower on the 1st day (486 msec) in comparison with the final day (456 msec). Thus, the majority of the improvement in locating searched targets occurs for those trials with distractors in both the category-based and the identity-based search tasks.

One difference between Experiment 1 and Experiment 3 was the significant interaction between target group and target eccentricity for trials without distractors in Experiment 3 [$F(2,8) = 9.5505$, $p < .05$]. This effect stems from the fact that there was no RT difference across target groups for targets at 3° (HSD; $p < .05$), but responses to searched targets were faster than responses to isolated targets at 6° and at 9° (HSD; $p > .3$).

Main test phase. On the day of the main test block, a set of unfamiliar targets was added to the final target training block. RTs for each of the three target groups are shown in the inset of Figure 2. A one-way (target group) repeated measures ANOVA showed that there was no significant RT difference across target groups during this final target training block [$F(2,8) = 0.67257$, $p = .54$].

For the test block, a four-way (set size $\times$ target group $\times$ distractor group $\times$ target eccentricity) repeated measures ANOVA on RTs showed the expected main effects of set size [$F(2,8) = 32.048$, $p < .001$] and target eccentricity [$F(2,8) = 46.630$, $p < .001$] as well as an interaction between set size and target eccentricity [$F(4,16) = 21.853$, $p \ll .001$]. These effects indicate that search was slower in the presence of distractors and with increasing target eccentricity, and that the set size effect was larger for greater eccentricities.

The main effect of distractor group was significant [$F(1,4) = 11.492$, $p < .05$]. The subjects were faster at searching for targets among familiar distractors (661 msec) than for those among unfamiliar distractors (703 msec). The interaction between distractor group and set size was also significant [$F(2,8) = 5.8058$, $p < .05$]. Search slopes for familiar distractors (22.5 msec/item) were significantly less steep than search slopes for unfamiliar distractors (27.8 msec/item; Figure 9). Although the effect of distractor familiarity was relatively small in this experiment, these results support the findings of Experiments 1 and 2; familiarity of a distractor set enhances search efficiency in the context of complex images and inhomogeneous distractors.

For the test block, all target groups (searched, isolated, and unfamiliar) were directly compared across all factors. The main effect of target group [$F(2,8) = 7.9586$, $p < .05$] was significant. The subjects were significantly faster at locating searched targets (601 msec) than isolated (738 msec) or unfamiliar (708 msec) targets (HSD;

$p < .05$). Furthermore, there was a significant interaction of target group and set size [$F(2,8) = 6.4552, p < .01$], since search slopes were less steep for searched targets (16.2 msec/item) than for isolated targets (32.2 msec/item) or unfamiliar targets (27.1 msec/item; Figure 9). Surprisingly, there were no significant differences between isolated and unfamiliar targets in RT or search slope. The difference between searched and isolated targets replicates the finding of Experiment 1: The context and frequency of a subject's experience with certain images created a distinction between the target groups. The most likely explanation is that the subjects biased their search toward the target candidates that they encountered most often.

There was a significant interaction between target group and target eccentricity [$F(4,16) = 3.1025, p < .05$]. At 3° eccentricity, there was no significant difference in RTs between searched (522 msec) and unfamiliar (540 msec) targets (HSD; $p > .9$). However, the subjects were significantly faster at locating searched targets than unfamiliar targets at 6° (570 vs. 703 msec, respectively) and 9° (710 vs. 880 msec, respectively) eccentricities (HSD; $p < .01$). The slopes for searched and unfamiliar targets were also similar at 3° (10.2 vs. 9.4 msec/item, respectively) but not at 6° (11.5 vs. 26.3 msec/item, respectively) or 9° (26.5 vs. 54.3 msec/item, respectively). However, this difference was only marginally significant [set size $\times$ target group $\times$ target eccentricity; $F(8,32) = 2.0867, p = .067$].

The results of Experiment 3 indicate that, in general, familiarity with a target enhances search performance in our paradigm. In no case was search for unfamiliar targets better than search for searched targets. However, our results also indicate that the effects of target familiarity can be offset by a subject's expectations. Search for isolated targets was not significantly different from search for unfamiliar targets. It is clear that the effects of target familiarity depend on how subjects have experienced all possible targets.

GENERAL DISCUSSION

The ease with which we can find a known target in a visual array depends on a number of task parameters. A subject's performance on a particular search task may be based on knowledge of what to look for, what not to look for, how to look, or a combination of all of three factors. In the present study, we investigated the extent to which distractor familiarity, target familiarity, and target experience affect performance in a visual search task involving more complex and varied stimuli than those of previous studies. We found that familiarity with a distractor set, gained through search experience, led to more efficient searches even when the target itself was highly familiar. We also found that target familiarity improved search performance, although this effect could potentially be outweighed by a subject's expectation of which targets were most likely to appear. The results of the present experiments are consistent with the hypothesis that stimulus familiarity promotes more efficient processing of experienced visual objects.

Distractor Familiarity

Wang et al. (1994) proposed that a familiarity difference between target and distractors, in which the distractors are familiar but the target is not, can lead to parallel, efficient search. However, since they used each target with only one type of distractor, their comparisons spanned different stimulus pairings whose low-level features were not controlled. Malinowski and Hübner (2001) and Shen and Reingold (2001) controlled the low-level features of stimulus pairings by using groups of subjects who had different degrees of experience with their stimuli. For example, Malinowski and Hübner compared German-speaking subjects (familiar with N) and Slavic-speaking subjects (familiar with N and mirror- N). In both studies, search slopes in the presence of familiar distractors were less steep than those in the presence of unfamiliar distractors, even when the target was familiar. The authors concluded that distractor familiarity itself, rather than a familiarity difference between target and distractors, is what enhances search performance.

In this study, we investigated the extent to which distractor familiarity enhances visual search under more natural conditions: complex stimuli and inhomogeneous distractors. We asked subjects to search for 1 of 20 targets among a varying number of distractors. Over the course of a 4- to 5-day period, performance improved dramatically and searches were carried out more efficiently. We then introduced an unfamiliar set of distractors and compared RTs and search slopes for the new set of distractors with those for the distractor set used during all previous search trials. None of our paradigms led to parallel search conditions in the strictest sense, which is not surprising given the complexity of the stimuli. Nonetheless, we found more efficient searches in the context of familiar distractors even when targets were overlearned and thus highly familiar. This effect was maintained when the target had been experienced only in isolation, indicating that it cannot be accounted for by contextual cuing (Chun & Jiang, 1999). These data support the conclusions of Malinowski and Hübner (2001) and Shen and Reingold (2001) that distractor familiarity alone improves visual search, and extend this finding to more natural settings.

Given these results, an important question that arises is why distractor familiarity enhances search performance. One theory suggests that familiarity leads to an ability to group distractors (Karni & Sagi, 1991; Malinowski & Hübner, 2001), which aids in target detection (Duncan & Humphreys, 1989; Treisman, 1982). Since we found the effect while using inhomogeneous distractors, our results might suggest that familiarity itself can act as a feature across which stimuli can be grouped. However, grouping familiar stimuli together would make search difficult, given the fact that the targets were highly familiar in almost all cases.

Another possibility is that subjects learned to search for a subset of stimulus features that differed across targets and distractors. In our experiments, there were at least 20 targets and 20 familiar distractors and the specific target

and distractor images were randomized across subjects. Therefore, it is unlikely that the effects of familiarity can be accounted for by low-level feature differences between stimuli. It is also unlikely that the subjects developed an improved search strategy and searched for those features that would best divide the target and distractor groups in some arbitrary stimulus space. When two independently learned distractor groups were mixed, search performance was not significantly affected.

The present experiments are consistent with the hypothesis that familiar visual objects are processed more efficiently. More efficient processing may entail faster identification and analysis of objects (rejection of distractor or confirmation of target) or an increase in the number of simultaneously processed items. These alternatives are not easily distinguishable, but there is evidence supporting the hypothesis of an expanded processing window for visual stimuli in the presence of familiar distractors. Greene and Rayner (2001) used a task similar to that of Wang et al. (1994) and found that fixation durations were similar for familiar and unfamiliar distractors, indicating that the time to process each fixated object was constant. Furthermore, subjects made fewer fixations in the presence of familiar distractors, and a gaze-contingent window limiting the area of visual stimulation had a greater effect on search in which familiar distractors were used than on search in which unfamiliar distractors were used. Thus, peripheral information was more important in the presence of familiar distractors, where it was used to guide saccade target selection more efficiently. Others have shown that the "useful field of view"—that is, the region of visual space over which information can be processed during a single fixation—is dynamic and can increase in size after training (Ball, Beard, Roenker, Miller, & Griggs, 1988).

Regardless of the mechanism, familiarity-related changes in processing efficiency must, by definition, develop through experience. All of the specific images used in the present experiments were initially novel. Extended experience led to enhanced search performance, which we attribute to more efficient processing of familiar items even though explicit recognition of the distractors was not required for the task (see also Williams, Henderson, & Zacks, 2005). The complex stimuli used in these experiments may be particularly susceptible to familiarity effects. These effects may be a direct result of experience-dependent changes in receptive field properties of neurons in visual areas involved in recognition (Kobatake, Wang, & Tanaka, 1998; Logothetis, Pauls, & Poggio, 1995; Miyashita, Date, & Okuno, 1993; Rolls, Baylis, Hasselmo, & Nalwa, 1989; Sigala & Logothetis, 2002). To fully account for these behavioral and neural data, comprehensive models of visual search need to incorporate dynamic variables related to experience-dependent neural processing. This is particularly important given the fact that we observed significant behavioral changes over the course of a few hours of search experience, and that improvement was still observed after multiple days of practice.

Target Familiarity

Unlike in previous studies, we asked subjects to search for 1 of 20 targets, and thus the subjects could not form a single template of the target prior to the search. Our paradigm therefore offers the opportunity to study how target familiarity affects visual search. By instructing the subjects to search for any image belonging to a target category (such as butterflies), we could introduce unfamiliar exemplars without overtraining.

In general, target familiarity enhanced search performance, but this effect could be counteracted by the specifics of target experience. When our subjects searched for unfamiliar targets, we found that search was usually inefficient. The one exception occurred with small target eccentricities, where search for familiar and unfamiliar targets was equally efficient. However, under no condition was search for an unfamiliar target more efficient than search for a familiar target.

Our results regarding target familiarity may seem at odds with the conclusions of Wang et al. (1994), Malinowski and Hübner (2001), and Shen and Reingold (2001). Their data indicate that target familiarity did not affect search efficiency or (in some cases) led to less efficient search. However, in all three previous studies a single target was used in a block of trials, allowing the subjects to maintain a mental template of the search target. This method may obscure any benefits of target familiarity. The targets in our task were randomized on a trial-by-trial basis, limiting the expectations of our subjects. Furthermore, inhomogeneous distractors increased task difficulty, and thus the subjects were less likely to exhibit ceiling performance. Finally, in previous studies line drawing stimuli were used, the familiarity of which was defined according to their associations with particular languages. In the present study, we controlled familiarity through task experience, and our results are not confounded by special processing mechanisms for letters and numbers. All of these differences may have allowed target familiarity effects to emerge in Experiment 3.

Target Experience

Although target familiarity affected search performance, the subjects' experience with a target had a greater impact on performance. The subjects were sensitive to the number of presentations of individual targets during the experiment and responded more quickly to those targets that had been seen in over 75% of the search trials. Explicitly or implicitly, the subjects apparently learned to expect one subset of targets more often than another, and this effect was exaggerated by the presence of distractors. This expectation may have masked the effect of target familiarity for images previously experienced in isolation.

Although there was a difference between target groups in terms of the context of the subjects' experience in Experiments 1 and 3, we did not find any evidence of a contextual cuing effect in our paradigm. In Experiment 2, the subjects experienced two separate target-distractor group

pairings during the initial search trials, and their performance was not affected by crossing of the target and distractor groups or by mixing of the distractor groups.

Conclusions

The results from the present set of experiments are consistent with the idea of a continuum of search difficulty dependent on target and distractor qualities (Duncan & Humphreys, 1989; Nakayama, 1990; Treisman, 1993; Wolfe, 1998). The least efficient searches, in terms of RT and search slope, occur when targets and distractors are both unfamiliar. Distractor familiarity, target familiarity, and experience searching for specific target images all improve search performance. The most efficient searches occur when targets previously searched for are located among familiar distractors. This continuum suggests that in an environment in which objects are not labeled as targets or distractors, it is beneficial to implicitly encode experienced regularities, not only because they may be searched for later but also because such knowledge can allow these objects to be quickly analyzed and dismissed.

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