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Spatial context learning in visual search and change detection

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Humans conduct visual search more efficiently when the same display is presented for a second time, showing learning of repeated spatial contexts. In this study, we investigate spatial context learning in two tasks: visual search and change detection. In both tasks, we ask whether subjects learn to associate the target with the entire spatial layout of a repeated display (configural learning) or with individual distractor locations (nonconfigural learning). We show that nonconfigural learning results from visual search tasks, but not from change detection tasks. Furthermore, a spatial layout acquired in visual search tasks does not enhance change detection on the same display, whereas a spatial layout acquired in change detection tasks moderately enhances visual search. We suggest that although spatial context learning occurs in multiple tasks, the content of learning is, in part, task specific.

Recent studies suggest that normal adults can rapidly acquire spatial contextual knowledge. For example, when subjects search for a T target among L distractors, search speed is faster for displays that have previously been seen than for novel displays (Chun & Jiang, 1998; for a review, see Chun, 2000). The distractor locations on repeated displays form a consistent visual context, which guides spatial attention to the associated target's location. Such learning, known as *contextual cuing*, is surprisingly powerful. It occurs after just five or six repetitions and lasts for at least a week (Chun & Jiang, 2003; Jiang, Song, & Rigas, 2005). It is also implicit, because subjects rarely notice the repetition, nor can they recognize repeated displays after learning.

What have people learned from a repeated visual search display? Subjects may learn the global spatial layout—the imaginary outline pattern formed by all the items—and know that whenever a given configuration is presented, the target will be in the upper left corner. Alternatively, subjects may learn part of the display or even individual locations. Chun and Jiang (1998) hypothesized that people benefit from repeated displays in visual search because they have learned the global layout—the configuration—of repeated displays. Such a layout includes interitem spatial relationships, in which individual items are represented with reference to one another (Wolfe, 1998a). Configural processing is seen in object tracking (Yantis, 1992) and visual working memory (Jiang, Olson, & Chun, 2000; Phillips, 1974). It allows multiple individual items to be organized into a larger chunk, simplifying the encoding of individual locations.

To find out whether subjects can learn the global layout, Jiang and Wagner (2004) first trained subjects to conduct visual search among displays centered at fixation. After they had seen a given display 20 times, the subjects were tested in a transfer session, during which the previously learned displays were now rescaled (expanded or contracted) and shifted (left, right, up, or down). Even though individual item locations no longer matched those seen during training, the subjects still searched more quickly from rescaled and shifted displays than from novel displays, suggesting that preserving the learned configuration permits transfer.

Contextual learning in visual search also has a nonconfigural component, however. When subjects were trained on two sets of distractor layouts, both of them associated with the same target location, their learning transferred completely to a recombined layout, which was created by swapping the locations of a random subset of distractors from one trained layout with those of the other trained layout (Jiang & Wagner, 2004). The recombined display produced an entirely different global layout, since the interitem spatial relationships had changed, but each individual distractor had previously been associated with the target's location. The complete transfer of learning to the recombined condition suggests that visual search supports nonconfigural association, as well as configural learning (see also Chun & Jiang, 1998; Jiang & Chun, 2001; Olson & Chun, 2002).

The Present Study

The main purpose of the present study was to investigate whether learning of repeated spatial context occurs in multiple tasks. Up to now, spatial context learning has been examined with visual search tasks only. Yet in real-world spatial navigation, we often carry out a variety of visual tasks within a spatial layout. Sometimes we

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glimpse at a scene, searching for a particular friend (visual search); sometimes we look for an unspecified item that has changed from one moment to the next (change detection); and other times we simply look. Because a given spatial layout may be processed in multiple tasks, it is important to test the generality of contextual cuing to tasks other than visual search. Furthermore, to the extent that we often conduct different tasks within the same spatial layout, it is of empirical interest to study the transfer of spatial context learning across tasks.

Change detection has been used to study visual attention and working memory (Rensink, 2002). In this task, subjects are first shown a visual display for a brief period of time; then after a short interval (typically, 1 sec), another visual display is presented. The two displays are similar except for one change. Using natural scene images, Rensink, Simons, and others have found that it is surprisingly difficult to detect changes, even though the change is visually salient once it has been pointed out (Rensink, O'Regan, & Clark, 1997; Simons & Levin, 1998). Using simplified stimuli, such as colors and letters, Luck and Vogel showed that change detection deteriorates when the number of items per display is greater than four (Luck & Vogel, 1997; Pashler, 1988; Phillips, 1974). These studies have highlighted the surprising limitations of the visual system in the representation of details. Our first goal in this study was to examine whether change detection improves with repeated visual displays.

A further goal of this study was to test whether the content of learning is task specific. On the one hand, the spatial layout of a display can be extracted independently of the task the subjects perform. For instance, a city scene remains the same scene whether one is searching for a friend or detecting a change. So one may expect learning of the spatial layout to be independent of the task. On the other hand, a given display may be represented differently depending on how one initially processes the display. Some tasks emphasize the global configuration, others individual locations. These differences may limit any transfer between tasks. To address this question, we tested whether a spatial layout learned in visual search would enhance change detection with the same layout, and vice versa. We also tested the role of configural and nonconfigural learning in visual search and change detection.

In Experiment 1, we replicated contextual cuing in a visual search task and showed that once subjects had learned two visual search displays that shared the same target location, learning transferred to a recombined display. This suggests that nonconfigural associations support spatial context learning in visual search.[1] In Experiment 2, we tested whether contextual cuing would occur in a change detection task and whether learning was also partly nonconfigural. In Experiment 3, we trained subjects on repeated displays, half in a visual search task and half in a change detection task, and tested whether learning transferred between tasks. Finally, in Experiment 4, we tested transfer of learning across tasks for recombined displays.

EXPERIMENT 1
Spatial Context Learning in Visual Search

In this experiment, subjects searched for a T target among rotated L distractors. The experiment was divided into two phases, running consecutively: a training phase and a transfer phase. In the training phase, the subjects were trained on 36 displays, each presented once per block for 20 blocks. Each display contained 1 target location (T) and 10 distractors that formed a spatial layout. There were 18 target locations, with two different distractor layouts for each target, which produced a total of 36 displays. By the end of the training session, the subjects had searched through the 36 displays 20 times. New displays were not tested in the training phase.

The transfer phase included three conditions: *old*, *new*, and *recombined*. The old displays were the same as the 36 trained displays. The new displays contained the trained target locations and novel distractor layouts. The difference between *new* and *old* conditions provided us with a measure of spatial contextual cuing. Finally, the recombined displays were created by swapping a random half of two trained displays that shared the same target location. For example, if a given target was presented within Distractors {1–10} on one trained display and Distractors {11–20} on another trained display, the recombined display might contain the target plus Distractors {1–5, 11–15}. Because the entire trained layout was preserved in the *old* condition, but not in the *recombined* condition, their difference reflected whole layout learning. Conversely, because each individual distractor had previously been paired with the target in the *recombined* condition, but not in the *new* condition, their difference reflected nonconfigural learning. Figure 1 shows a schematic sample of the displays.

On the basis of previous studies, we predicted that in the transfer phase, the subjects would respond more quickly in the *old* than in the *new* condition, showing contextual cuing (Chun & Jiang, 1998). We also predicted that learning would transfer to the *recombined* condition, showing significant nonconfigural learning (Jiang & Wagner, 2004).

Method

Subjects. In this study, the subjects were students at Harvard University, 19 to 28 years of age. All had normal or corrected-to-normal visual acuity. They indicated informed consent before the experiment.

Thirteen subjects participated in Experiment 1.

Equipment. The subjects were individually tested in a room with dim interior lighting. They viewed a computer screen from an unrestrained distance of about 57 cm, at which distance 1 cm corresponds to 1º of visual angle.

Materials. Each visual search trial contained 11 items: 1 T target and 10 rotated L distractors. Each item included two line segments that formed either an L or a T (0.9º). The target, a unique T presented among Ls, was rotated 90º to the left or to the right. The distractors were randomly rotated 0º, 90º, 180º, or 270º. The subjects pressed a left key for a leftward T and a right key for a rightward T. Items were presented in white on a midgray background. They were positioned

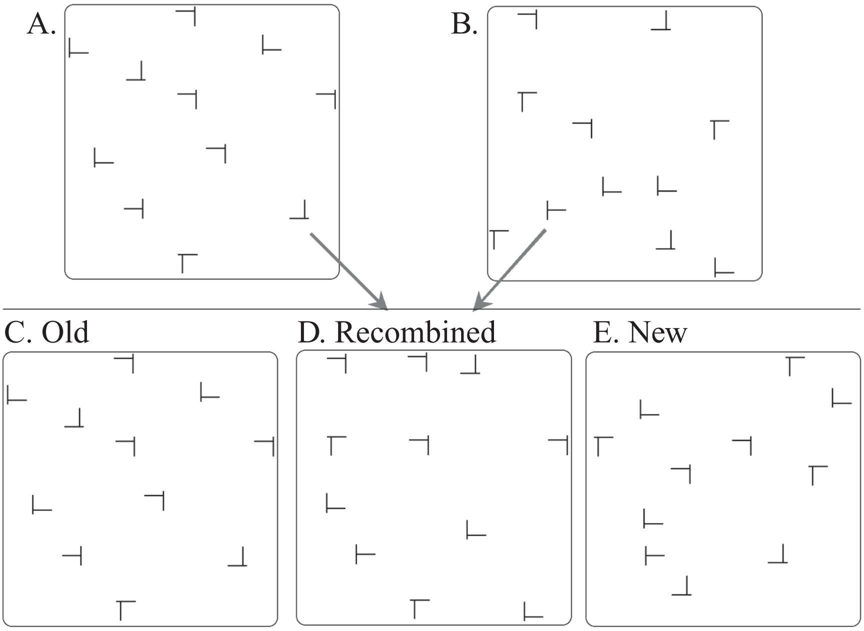

Figure 1. A schematic demo of displays used in Experiment 1. Panels A and B show two visual search displays during the training phase. The two displays share the same target location. Subjects searched for a rotated T target presented among L distractors and identified the direction of the T. Panels C, D, and E are three transfer conditions. The recombined display is created by swapping random halves of two trained distractor sets.

randomly within an invisible 12 × 8 grid matrix that subtended 23.4º × 15.6º.

Design. The experiment included two phases: a training phase (20 blocks, each including 36 trials) and a transfer phase (1 block of 108 trials). Prior to the training blocks, 18 unique target locations were randomly chosen. Each target location was associated with 20 randomly selected distractor locations, divided into two sets of 10 locations. Each set of 10 was paired with the target location once per block. Thus, the target may be paired with distractors at Random Locations {1–10} on one trial and distractors at Random Locations {11–20} on another trial. The *new* condition was not tested during training, because we were constrained by the total number of trials we could fit within a session. Previous studies in which such a design—training on repeated displays only—has been used have shown implicit visual learning (e.g., Jiang & Wagner, 2004; Olson & Chun, 2001).

The transfer phase immediately followed the training, and it included three conditions: *old*, *new*, and *recombined*, each with 36 trials. The old displays were the same as those seen during training. The new displays contained the same 18 target locations (each appearing in 2 trials) with new distractor locations. The recombined displays contained a random half of one trained distractor set and a random half of another trained distractor set. Thus, the target may now be paired with distractors at Locations {1–5, 11–15} on one trial and with distractors at Locations {6–10, 16–20} on another trial. All the conditions were randomly intermixed.

Trial sequence. The subjects pressed the space bar to initiate each block. Each trial started with a fixation point for 600 msec, followed by the search display, which was presented until a response was made. Incorrect responses were followed by a sad face icon. One second later, the next trial was presented.

Results

During the training phase, mean accuracy ranged from 93% to 97% in different blocks. It did not vary significantly as a function of block [$F(19,228) = 1.55, p > .15$]. During the transfer phase, mean accuracy for the *old*, *new*, and *recombined* conditions was 97%, 94%, and 96%, respectively. They were not significantly different from one another [$F(2,24) = 2.73, p > .08$].

Analysis was focused on correct trials only. The median reaction time (RT) for each subject was entered into statistical analyses.

Figure 2 (left) shows the group mean RT during the training phase. The main effect of block was significant [$F(19,228) = 6.19, p < .001$], showing a significant improvement in search RT as the experiment progressed. Such learning may reflect a combination of general learning in visual search and specific learning of repeated displays.

Figure 2 (right) shows the group mean RT during the transfer phase. The three conditions were significantly different from one another [$F(2,24) = 5.21, p < .02$]. Planned contrasts showed that RT was significantly longer in the *new* condition than in the *old* condition [$t(12) = 2.48, p < .03$], showing a contextual cuing effect. RT was also significantly longer in the *new* than in the *recombined* condition [$t(12) = 2.94, p < .01$], suggesting that preserving nonconfigural association between the target and the distractors was beneficial. Finally, RT was not significantly different between the *old* and the *recombined* conditions [$t(12) = 0.33, p > .50$], suggesting that preserving the entire learned layout did not additionally enhance visual search.

Discussion

In Experiment 1, we replicated previous findings of contextual cuing in visual search. After training the subjects on 36 repeated displays that included 18 target loca-

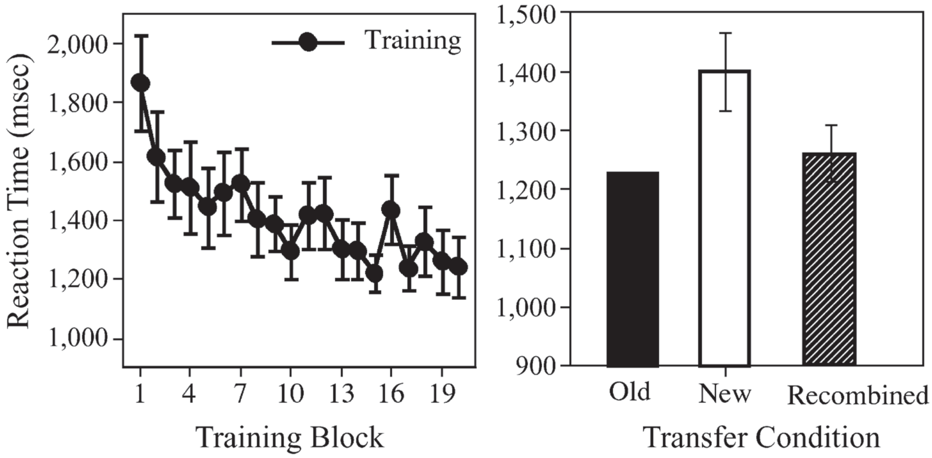

Figure 2. Results from Experiment 1. The left panel shows the training phase (error bars represent between-subjects standard error). The right panel shows the transfer phase (error bars represent the standard error of the difference between each condition and the *old* condition).

tions, we found that the subjects were significantly faster searching the previously trained displays than the novel displays. In addition, the subjects were just as fast searching through recombined displays as through trained displays, even though the recombined displays did not match the trained displays in their exact spatial layout. These findings suggest that nonconfigural associations between a subset of the context (such as individual distractor locations) and the target are sufficient to cue visual attention to the target's location.

EXPERIMENT 2
Spatial Context Learning in Change Detection

Can we generalize spatial contextual cuing to tasks other than visual search? If we can, will learning also show a significant nonconfigural component? To address the generality of contextual cuing, in Experiment 2 a design similar to that in Experiment 1 was used, except that a change detection task was employed.

On each trial, the subjects were presented with a memory display that contained 11 dots. After a brief retention interval, a probe display that contained 12 dots was presented (Figure 3A). Two of the dots on the probe display were labeled: one at a previously occupied location (*target*), the other at a previously unoccupied location (*filler*). The subjects were asked to judge which of the two labeled locations had previously been *occupied*. Other dots not labeled were at the same locations as in the memory display. Thus, the memory and the probe displays differed only in the addition of one location.

The subjects were tested in a training phase that included 20 blocks and a transfer phase of 1 block. In the training phase, the displays were repeated across blocks. The target and the filler locations also were repeated. They were presented on two different displays per block. On 1 trial, the target location was accompanied by Locations {1–10}; on another trial, the target location was accompanied by Locations {11–20} (Figure 3A). There were 36 trials per block, including 18 unique pairs of target and filler locations.

Three conditions—*new*, *old*, and *recombined*—were tested in the transfer phase. The *old* condition included 36 trials that were the same as those shown during training. The *new* condition included 36 trials of the same target and filler locations, but they were accompanied by 10 new distractor locations (Figure 3B). The *recombined* condition included 36 trials of the same target and filler locations and a recombined distractor set. Half of the distractor set was chosen from one trained display (e.g., Locations {1–5}), and the other half from the other trained display (e.g., Locations {11–15}). Thus, the *recombined* condition contained a new layout, but each location within the layout had previously been paired with the target location (Figure 3B).

If spatial contextual cuing is a general mechanism not restricted to visual search, accuracy in detecting changes should be higher among old displays than among new displays. In addition, if nonconfigural learning plays a similar role in all tasks, we should expect learning to transfer to recombined displays.

Method

Subjects. Ten students participated in this experiment.

Materials. Each trial included a memory display (400 msec), a blank interval (1,000 msec), and a probe display (until response).

The memory display contained 11 items, presented at randomly selected locations within an invisible 12 × 8 matrix (23.4º × 15.6º). Each item was a white filled circle (0.8º). One of the 11 items would be labeled on the probe display, whereas the other 10 would not be labeled. The labeled item from the memory locations was the *target*, and the others were *distractors*. The probe display contained 12 items; all but 1 were the same as those in the memory display. The newly added item was also labeled. This item was chosen at random, but once chosen, it remained at the same location whenever the target was presented. This item will be referred to as the *filler*. The target and the filler were labeled as "1" or "2," randomly determined on each trial. The digits were printed in black against white dots, making the two labeled dots immediately perceivable when the probe display was presented. The subjects were told to choose the

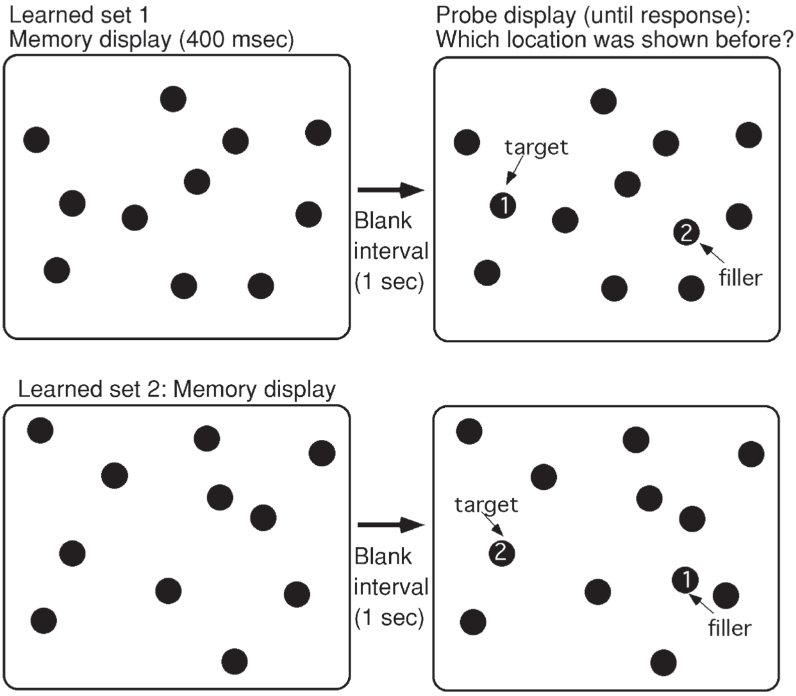

Figure 3A. A sample display of two trained sets in Experiment 2.

location that did not change and to press the corresponding digit. Figure 3A shows a sample display.

Design. The experiment was divided into 20 blocks of training (36 trials each) and 1 block of transfer (108 trials). Prior to the training blocks, 18 target locations were randomly drawn from a 12×8 invisible grid. For each target location, 20 distractor locations were randomly chosen and divided into two sets of 10 locations. Each set of 10 was paired with the target location once per block. The 36

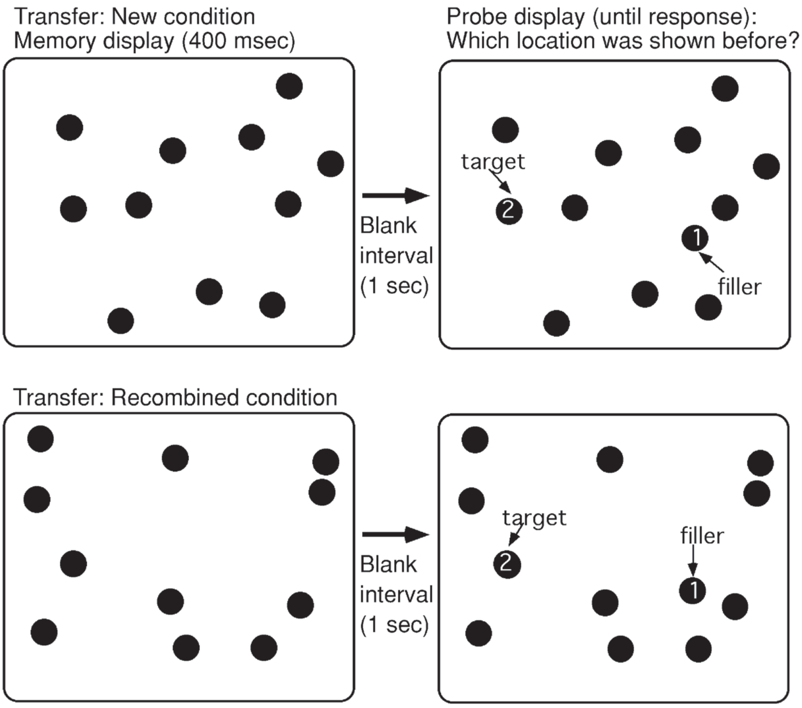

Figure 3B. A sample display of a *new* condition in Experiment 2 and a recombined display produced by recombining half of each trained set shown in Figure 3A.

trials were then intermixed in presentation, with the constraint that the target location would not be repeated on consecutive trials (see Figure 3A for a sample).

The transfer session then ensued. The 108 transfer trials were equally divided into three conditions: *old*, *new*, and *recombined* (see Figure 3B). The old displays were the same as those seen during training. The new displays contained the same 18 target locations and the same 18 filler locations, each appearing twice, paired with newly generated distractor locations. The recombined display contained the 18 target locations and the 18 filler locations, each appearing twice, paired with two different recombinations of the trained displays. Half of the distractors from each of the two trained sets were recombined to form one display, and the other halves from the two sets were recombined to form another display. The three conditions were randomly intermixed and were divided into three blocks. Note that no display was repeated during the transfer session. Consequently, any difference among the three conditions must be a result of contextual cuing acquired during the training session.

Trial sequence. Each trial started with a fixation point for 600 msec, followed by a memory display that lasted 400 msec, a blank interval of 1,000 msec, and a probe display that lasted until a response was made. The subjects pressed the 1 or 2 digit on the number board, corresponding to the digit labeling the unchanged location.[2] Accuracy feedback in the form of a happy or sad face icon was displayed after each response. The subjects were instructed to respond as accurately as possible. They were not informed of the repetition during training, nor were they given any special instructions before transfer.

Results

We calculated mean accuracy in the change detection task, and Figure 4 shows these results. During the training phase, mean accuracy improved gradually. The main effect of block was significant [$F(19,171) = 2.91$, $p < .01$]. Accuracy was around 60% when training started and improved to around 77% when training ended. This improvement may reflect a combination of procedural learning in change detection and specific learning of the repeated displays. Accuracy continued to improve from training to transfer: it was marginally higher in the *old* transfer session than in the last block of training [$t(9) = 2.23$, $p < .06$].

An ANOVA on transfer condition (*old*, *new*, and *recombined*) revealed a significant difference among the three conditions [$F(2,18) = 5.55$, $p < .02$]. Planned contrast showed that accuracy was significantly higher in the *old* (82%) than in the *new* (75%) condition [$t(9) = 2.49$, $p < .03$], suggesting that contextual cuing occurred in a change detection task. Accuracy in the *old* condition was also significantly higher than that in the *recombined* condition [72%; $t(9) = 3.19$, $p < .01$], suggesting that preserving the entire learned layout was critical for contextual cuing. Finally, the *new* and *recombined* conditions did not differ significantly from each other [$t(9) = 0.82$, $p > .40$], suggesting that the preservation of nonconfigural learning alone was insufficient for cuing. Spatial context learning in the *old* condition failed to generalize to the *recombined* condition.

Discussion

With a change detection task, Experiment 2 showed that change detection performance was better for repeated displays than for nonrepeated ones. This finding suggests that spatial contextual cuing applies not only to visual search, but also to change detection. To our knowledge, this is the first time that contextual cuing has been demonstrated in change detection tasks.

Even though spatial context learning occurs in change detection, Experiment 2 shows that what is learned in this task may be different from what is learned in a visual search task. In particular, after the subjects had learned two repeated displays, both of them associated with the same target location, learning did not transfer to a recombined display, formed by combining a random half of each trained display. The lack of transfer suggests that in change detection, subjects fail to learn nonconfigural association between individual distractor locations and the target. This observation can be contrasted with that for the visual search task in Experiment 1. In visual search, learning transfers from trained displays to recombined

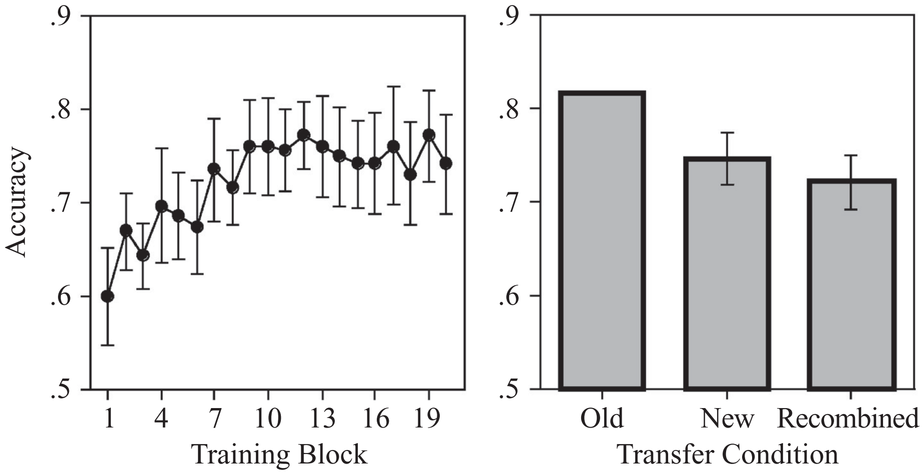

Figure 4. Results from Experiment 2. The left panel shows training data (error bars represent standard error of the between-subjects variance). The right panel shows transfer data (error bars represent the standard error of the difference between each condition and the *old* condition).

displays, suggesting that nonconfigural association is beneficial. Thus, nonconfigural learning plays a more significant role in visual search than in change detection. We will discuss possible reasons for task-specific learning in the General Discussion section.

EXPERIMENT 3
Transfer of Learning Between Visual Search and Change Detection

The last two experiments showed that although spatial context learning occurs in both visual search and change detection, it has a larger nonconfigural component in visual search than in change detection. To further test whether what is learned in contextual cuing is task specific, we examined whether a spatial layout learned during visual search would facilitate change detection in the same layout, and vice versa.

Previous studies have shown that contextual cuing can transfer across stimulus types. For example, Chun and Jiang (1998) trained subjects to search for 2 and 5 targets among ▭ shaped distractors. After the subjects had acquired contextual cuing, they were asked to search for 2 and 5 targets among rotated 2 and 5 distractors. The subjects showed immediate transfer, suggesting that contextual cuing was not tied to the distractor identities.

Even though contextual cuing can transfer across stimulus types, it may not transfer across tasks. If subjects have primarily acquired configural learning in one task and nonconfigural learning in another, they may not benefit from having learned a given display in a different task. The transfer-appropriate account predicts that transfer is determined by the match between what is learned and how a display is currently processed. This hypothesis has been shown to account for memory transfer effects in nonvisual domains (Roediger, 1990).

We trained subjects to search for a T target among L distractors on 18 trials and to detect a location change from two arrays of dots on the other 18 trials. There were 20 training blocks; the first half of each block was one task (e.g., visual search), and the second half of each block was the other task (e.g., change detection). Immediately after training, the subjects were tested in a transfer block that included three conditions: *old*, *new*, and *switched*. Half of the transfer block included visual search trials. In this case, the search elements were presented among locations previously learned during visual search (*old*), new distractor locations (*new*), or locations previously learned during change detection (*switched*). The other half of the transfer block included change detection trials. Here, dot arrays were presented among locations previously learned during change detection (*old*), new distractor locations (*new*), or locations previously learned during visual search (*switched*). Figure 5 shows a schematic sample of the design.

Method

Subjects. Thirteen students participated in this experiment.

Materials. The materials were similar to those used in Experiments 1 and 2. In the change detection task, each memory display contained 11 white dots, and each probe display contained 12 white dots. The subjects were asked to determine which of two labeled

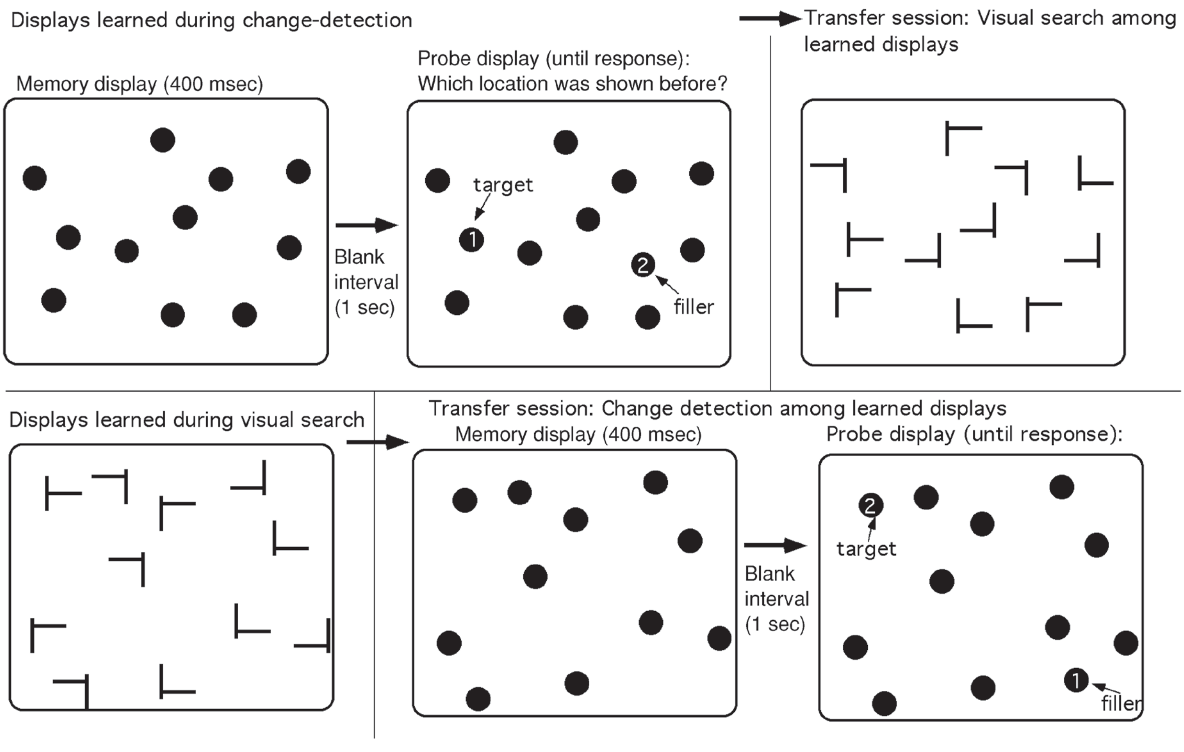

Figure 5. Sample displays from Experiment 3.

locations (including the new dot) had previously been shown on the memory display. In the visual search task, the subjects searched for a T target among 10 L distractors.

Design. Each subject was tested in 20 blocks of training (36 trials each) and 4 blocks of transfer (54 trials each). In the training phase, each block contained 18 visual search trials and 18 change detection trials. The two types of trials were presented in two subblocks: all visual search trials first, or all change detection trials first, randomly determined for each individual. The order of the subblocks was consistent across blocks for a given individual. The subjects were asked to press a space bar at the transition between the two tasks. We did not randomly interleave the two tasks, because we wanted to avoid frequent task switching.

Each display contained a designated target location. For visual search, this was where the T target was presented. For change detection, this was the location that would be probed (see Experiment 2). The other items were distractor locations. They contained the L distractors and dots whose locations would not be probed. The entire display (including which location contained the target) was repeated across blocks.

In the transfer phase, there were two blocks of visual search, interleaved with two blocks of change detection. Each block contained 54 trials, evenly and randomly divided into three conditions: *new*, *old*, and *switched*. In visual search blocks, the display locations previously learned during visual search were old, and the display locations previously learned during change detection were switched. In the change detection blocks, the arrangement was reversed. New and old displays shared the same target locations, but the distractor locations were newly generated on each trial for the *new* condition. Because a single block would contain only 18 trials per condition, we repeated all the trials (including the new displays) for a second block, to increase statistical power.

Results

Training. Accuracy in the change detection task improved as training progressed [Figure 6; $F(19,228) = 4.64$, $p < .01$]. Median RT (correct trials only) in the visual search task also decreased as training progressed [$F(19,228) = 7.35$, $p < .01$]. Visual search RT in this experiment was much longer than that in Experiment 1, perhaps as a result of the interleaving of visual search with change detection.

Transfer. Figure 7 shows the results from the transfer phase.

(1) *Visual search*. An ANOVA on transfer condition (*new*, *old*, and *switched*) showed a significant main effect of condition [$F(2,24) = 10.35$, $p < .001$]. When the transfer test was a visual search task and the displays had previously been repeated during visual search, RT was 1,363 msec, which was significantly shorter than that for new displays not trained before [RT = 1,803 msec; $t(12) = 4.83$, $p < .01$]. But if the display had previously been repeated during the change detection task and now these locations contained visual search stimuli, RT was intermediate between those for the *old* and the *new* conditions (RT = 1,565 msec). The subjects responded significantly more slowly in the *switched* condition than in the *old* condition [$t(12) = 2.25$, $p < .05$] and significantly more quickly in the *switched* condition than in the *new* condition [$t(12) = 2.20$, $p < .05$]. Thus, there was partial transfer from displays that had been learned during change detection to visual search (Figure 7).

(2) *Change detection*. An ANOVA test showed a significant main effect of transfer condition [$F(2,24) = 4.17$, $p < .028$]. When the transfer test was a change detection task and the displays had previously been repeated during change detection, accuracy was 81%, which was significantly higher than that in the new displays not trained before [accuracy = 73%; $t(12) = 3.11$, $p < .01$]. But if the display had previously been repeated during visual search and now these locations contained change detection stimuli, accuracy (72%) was not statistically different from that in the *new* condition [$t(12) = 0.24$, $p > .50$] but was significantly lower than accuracy in the *old* condition [$t(12) = 2.67$, $p < .02$]. Thus, there was no transfer from displays that were learned during visual search to change detection.

Discussion

To further assess whether spatial context learning was task specific, in Experiment 3 we examined whether spatial locations learned during visual search transfers to a change detection task, and vice versa. If the distractor locations were learned and associated with the target's location in an entirely task-independent manner, learn-

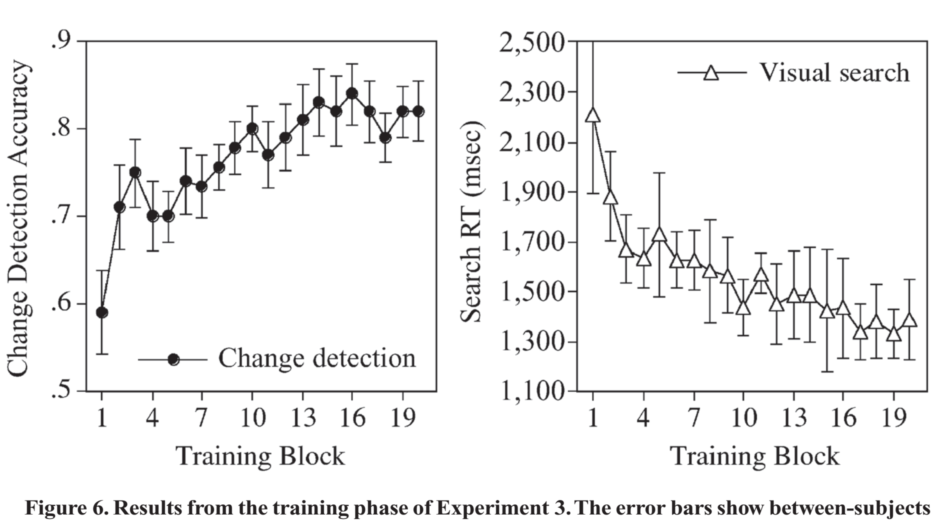

Figure 6. Results from the training phase of Experiment 3. The error bars show between-subjects standard error.

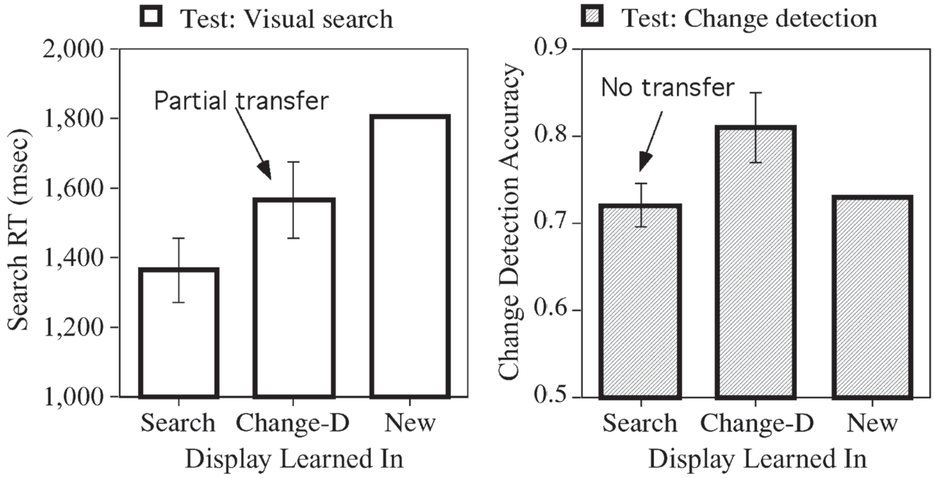

Figure 7. Results from the transfer phase of Experiment 3. The error bars show standard error of the difference between that condition and the *new* condition. Change-D, change detection.

ing should transfer across tasks. Instead, we found that visual search was facilitated more by a display that had previously been learned in visual search, rather than in change detection. In addition, change detection was not facilitated by a display previously learned in visual search. These findings suggest that whether subjects will benefit from a repeated layout depends on the match between the task they previously carried out and their current task, consistent with the transfer-appropriate account.

EXPERIMENT 4
Transfer Between Tasks for Recombined Displays

So far, we have argued that whereas visual search results in nonconfigural learning, change detection results in configural learning. This conclusion was derived by comparing the recombined displays with the old and new displays. After having been trained in a change detection task, subjects did not show transfer of learning to recombined displays, suggesting that local association was insufficient for change detection. But why did learning fail to transfer to recombined displays? Is it because change detection supports only configural learning (as was argued in Experiment 2), or is it because nonconfigural learning is expressed only in a visual search task? The distinction between what is learned and which kind of learning can be expressed is important (Jiang & Leung, 2005). If the change detection task does not allow nonconfigural learning to be expressed, then even if subjects have acquired local association, their learning will not manifest unless it is tested in a visual search task.[3] To find out whether change detection prevents nonconfigural learning from occurring in the first place, or whether it simply prevents nonconfigural learning from being expressed, we carried out Experiment 4.

In this experiment, the subjects were trained in a change detection task involving 36 displays that were associated with 18 target locations. After 20 blocks of training, the subjects were tested with new, old, and recombined displays, but the task employed during transfer was visual search. This design was thus similar to that in Experiment 2, except that the transfer phase involved a visual search task. If nonconfigural learning is never acquired with change detection, learning should not transfer to recombined displays even when the test is done with visual search. Conversely, if nonconfigural learning is acquired but is not expressed in change detection, learning should transfer to recombined displays when the test is done in visual search.

Method

Subjects. Fifteen new subjects participated in this experiment.

Design and Procedure. This experiment was similar to Experiment 2. The subjects were first trained on 36 change detection displays associated with 18 target locations, in that a given target location was presented on 2 trials. After 20 blocks of training, they were tested with a transfer block that contained 108 trials, randomly and evenly divided into three conditions: *old*, *new*, and *recombined*. The recombined displays were created by recombining half of 2 trained displays that shared the same target location. The only difference between this experiment and Experiment 2 was that in the transfer phase, a visual search task was used. The trained locations now contained T and L search items, with the T presented at the target locations.

Prior to the experiment, the subjects received 72 trials of visual search. This was done in order to ensure that they would be familiar with visual search during the transfer phase of the experiment.

Results and Discussion

We measured change detection accuracy during the training phase and visual search accuracy and RT during the testing phase. Figure 8 shows the results.

The main effect of training block on accuracy was significant [$F(19,266) = 2.83$, $p < .001$]. Accuracy improved as the training progressed, reflecting procedural learning, as well as learning of the repeated displays.

In the transfer phase, visual search accuracy was high (99.2% for *old*, 97.6% for *new*, and 98.1% for *recombined*). We thus will report statistical analysis for median RT data. There was a significant main effect of condition on median RT [$F(2,28) = 4.37$, $p < .022$]. In particular, RT was shorter for old displays than for new displays [$t(14) = 2.89$, $p < .012$], replicating the result from Experiment 3 that learning in a change detection task could transfer to a visual search task. In addition, RT in the *recombined* condition was significantly longer than that in the *old* condition [$t(14) = -2.59$, $p < .021$], but not significantly different from the *new* condition [$t(14) = 0.572$, $p > .50$]. Thus, even when the transfer test involved visual search, there was no evidence of transfer to recombined displays. This suggests that change detection did not simply prevent nonconfigural learning from being expressed. Instead, nonconfigural learning was not acquired in the first place in a change detection task. This finding is consistent with our contention that spatial context learning can be task specific.

GENERAL DISCUSSION

Humans are very efficient at learning complex, repeated visual layouts. In visual search, target detection is enhanced when a given search display is repeated a few times, because the distractors surrounding the target form a visual context. Context learning guides spatial attention to the associated target location (Chun & Jiang, 1998). In this study, we have shown that spatial context learning applies not only to visual search, but also to change detection tasks. When subjects have to remember a few spatial locations for a brief amount of time, their performance is enhanced on repeated displays. To our knowledge, this is the first study reported in which contextual cuing has been observed in a change detection task.

Although both visual search and spatial change detection support contextual cuing, learning occurs differently in these two tasks. A given display can be encoded globally as a layout or configuration, in which individual items are represented in relation to one another. The display can also be encoded nonrelationally (e.g., as a subset of the display or as individual locations), using the computer screen or the viewer as the spatial reference frame. Thus, any repeated spatial display potentially affords two kinds of learning: configural learning and nonconfigural learning. By training subjects on two displays and testing them on recombined displays whose entire spatial layout does not match the trained ones, we are able to separate configural learning from nonconfigural learning. A recombined display differs from the original learning in the global layout but is similar to the learned displays in nonconfigural characteristics: Each distractor location has previously been associated with the same target.

Experiment 1 shows that learning transfers to the recombined condition in visual search, suggesting that subjects have acquired nonconfigural association between individual distractors and the target location. In contrast, Experiment 2 shows that learning does not transfer to the recombined condition in change detection, suggesting that subjects have learned each repeated display as a whole layout. Experiment 4 further shows that the lack of a transfer to the recombined condition should be attributed to a lack of local learning in change detection. The difference in the pattern of nonconfigural transfer observed in the two tasks suggests that the content of spatial context learning is somewhat task specific. Furthermore, Experiment 3 shows that a spatial layout learned during visual search fails to enhance change detection with the same layout and that a display learned during change detection only moderately enhances visual search. This provides further evidence that what the visual system learns from repeated displays depends on the task that subjects carry out on the displays.

Although our study has clearly shown that contextual cuing is somewhat task specific, it does not inform us as to which difference between the two tasks is critical for the differences in transfer. Because the two tasks differ in several respects, only further empirical research will elucidate the critical differences underlying learning. In the following paragraph, we shall list several differences. Such dis-

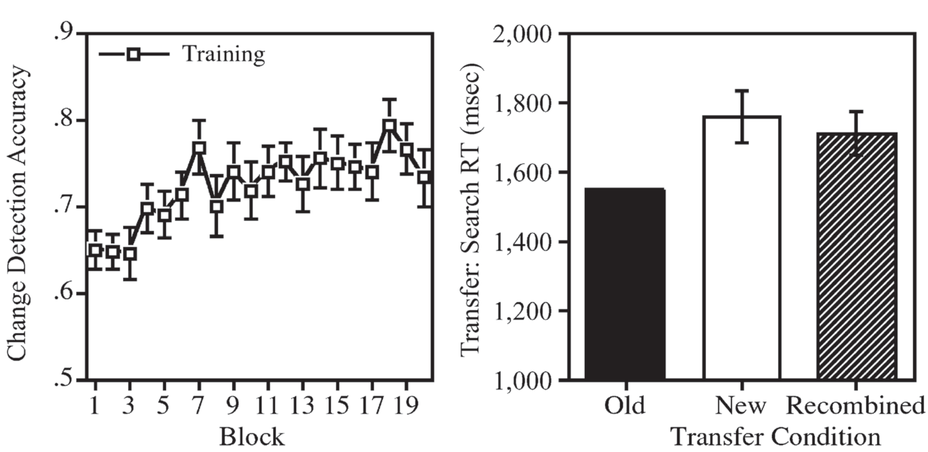

Figure 8. Left panel: Change detection accuracy during the training phase (error bars show between-subjects standard error). Right panel: Visual search reaction times (RTs) during the testing phase (error bars show the standard error of the difference between each condition and the *old* condition).

cussion is necessarily more speculative, but we hope it will provide a guide for future research by narrowing down the source of task specificity in contextual cuing.

To us, the most important difference between the two tasks lies in how attention is initially deployed on the display. Searching for a T among Ls entails serial deployment of attention. Distractor locations that are spatially proximate to the target (Olson & Chun, 2002) or that are searched immediately before the target is spotted (Olson & Chun, 2001) will be more strongly associated with the target than other distractors will. Thus, the nature of serial attentional deployment will make some portion of a global configuration more tightly associated with the target than are others, resulting in possible nonconfigural learning.[4]

In comparison, attention is deployed to the entire display more globally in change detection tasks. In such tasks, humans tend to impose chunking on randomly presented locations, so that when the probe display supplies the global configuration, change detection is facilitated (Jiang et al., 2000). Given that the entire configuration is encoded during training, it is perhaps not surprising that learning does not transfer to recombined displays in change detection. Thus, we propose that a main difference between visual search and change detection is in how a display is initially encoded. Visual search allows nonconfigural association to be established, whereas change detection primarily supports configural association.

Other differences between the two tasks may also contribute to task-specific cuing effects. First, in visual search the display is presented until a response is made, whereas in change detection the memory display is presented briefly (for 400 msec) and erased. The difference in duration of encoding can lead directly to a difference in learning. It can also indirectly affect learning, because learning is indexed by RT in visual search and by accuracy in change detection. Second, the locations are occupied by T/L items in visual search and by white dots in change detection. Even though the spatial configuration remains the same, learning may become tied to the identity of items (Jiang & Song, in press). Future studies in which similar item identity is used will clarify whether learning remains task specific.

Change detection places different demands on spatial attention than visual search does (Rensink, 2002; Wolfe, 1998b). These substantial differences are the main reasons why we initially selected this task, because it provides a strong test for the generality of spatial context learning. The presence of contextual cuing in this task suggests that the visual system possesses a spatial context learning mechanism that applies to multiple tasks.

Our study has gone beyond merely demonstrating spatial context learning in change detection. By testing the role of nonconfigural learning and the transfer of learning between visual search and change detection, this study reveals that spatial context learning can become task specific. We conjecture that what is learned—configural or nonconfigural associations—depends on how a display is initially encoded. Because we rarely have a bird's-eye view of an entire spatial layout, it is not surprising that visual search supports nonconfigural learning. Alternatively, the requirement of chunking all items into a large layout in change detection is congenial to configural learning in that task. Future studies should investigate whether other kinds of implicit learning, such as associative learning of object shapes (Chun & Jiang, 1999; Fiser & Aslin, 2001), are also task specific.

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NOTES

1. We note that configural learning and nonconfigural learning are not mutually exclusive. Nonconfigural learning is only one component of what subjects have learned in visual search.

2. We did not ask the subjects to press the digit corresponding to the changed location, because that location would appear only on the probe display. A correct response could be based on detecting the changed item or detecting the overlapped item. Regardless of which strategy was used, the requirement to respond to the overlapped item ensured that this location would be associated with the repeated display.

3. We thank Jennifer Stolz for raising this alternative hypothesis and for suggesting Experiment 4.

4. Note that serial search should not be equated with the extracting of local information, because the visual system is, in fact, capable of putting serially acquired information into a larger picture. For example, viewing a display through a moving aperture can lead to a percept of the whole scene behind the aperture (Palmer, 1999). Nonetheless, given that the visual system appears to build stronger associations for spatially and temporally more adjacent locations, serial search makes it likely that it will build nonconfigural associations.

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