Contextual cuing based on spatial arrangement of color

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Previous studies have demonstrated that, in visual search, repetition of a target's "context" significantly improves search performance (contextual cuing; Chun & Jiang, 1998). Context in those studies was defined as either spatial configuration or featural combination. In the present work, we demonstrate that repeating the spatial arrangement of object colors (conjunction of spatial configuration and featural combination) also leads to contextual cuing (Experiment 1). Experiments 2 and 3 rule out the possibility that the contextual cuing we find in Experiment 1 is caused only by the spatial configuration of color patches. Experiment 4 rules out the possibility that it is caused only by featural combination. Experiments 5 and 6 demonstrate that color-arrangement-based contextual cuing is an unconscious process. Experiments 7 and 8 demonstrate that contextual cuing seems to be more effective on chromatic (hue) variation than on achromatic (luminance) variation. In sum, our results demonstrate that contextual cuing is not merely associated learning in separate domains; it is a more integrated process than has perhaps been appreciated.

Physical judgments and actions constantly require us to process an amount of visual information far beyond the capacity of our conscious cognitive faculties. For this processing, we rely largely on powerful unconscious faculties. In a series of recent studies, Chun and colleagues have demonstrated that, in visual search, repetition of stimuli's spatial configuration–target location association can significantly improve performance (Chun, 2000; Chun & Jiang, 1998, 1999, 2003; Jiang & Chun, 2001; Olson & Chun, 2001, 2002; see also Hoffmann & Seibald, 2005; Ogawa, Takeda, & Kumada, 2004; Peterson & Kramer, 2001; Tseng & Li, 2004). Subjects searched for a unique, prespecified target among distractors. Typically, the experiments were organized in 24 blocks of 24 trials each. In each block, half the trials were repetitions of trials from previous blocks, so that each of 12 "old" displays was repeated 24 times in the course of the whole experiment. The other half of the trials in each block presented new displays. Old displays were defined as preserving spatial configuration—the locations of all items—whereas other properties (e.g., orientation of the items) were not necessarily preserved. As block number increased, old displays increasingly outperformed new displays. This suggests that subjects gradually learn associations between spatial configuration and target location. Recognition of a

repeated spatial configuration "guides" the subject to the target. What makes Chun et al.'s finding especially interesting is the unconscious nature of this contextual cuing: Subjects cannot consciously distinguish between old and new displays (Chun & Jiang, 1998)¹, nor consciously remember the target location in old displays (Chun & Jiang, 2003).

By identifying the kinds of feature information that facilitate contextual cuing, we may learn something about the contents of the unconscious memory. In addition to target location cuing by spatial configuration (Chun & Jiang, 1998), Chun and Jiang (1999) also found target feature cuing by the repetition of distractor features' combinations (see also Endo & Takeda, 2004). Therefore, it seems that the underlying memory keeps track of both spatial configuration and surface feature information. An important question that has not been addressed is whether the underlying memory stores this information together, as an entity, or separately. Asking whether contextual cuing will be elicited by the conjunction of the two can test this. That is the question in the present study.

Since the repetition of either spatial configuration or surface-feature combination can elicit contextual cuing, it may seem only natural that their conjunction should also elicit cuing. But in fact, the conjunction constitutes an entirely different set of information. From the extensive literature on the special problem of conjunction between different features (Green, 1991; Treisman & Gelade, 1980), it appears no more natural that contextual cuing should occur for the conjunction of spatial configuration and surface-feature combination than that it should not occur, even though each of those features individually elicits cuing. Consider one example on the issue of visual attention and feature processing with stimuli that closely

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resemble ours (color arrangement; explained below): Distinguishing between “white over black” and “black over white” requires focal attention, even if the colors, when given alone, would be easily processed in parallel.

Endo and Takeda (2004) have also recently studied the relationship between spatial-configuration cuing and surface-feature cuing. But our question here is significantly different from theirs. They tested a situation in which contextual cuing can be based on both spatial configuration and surface-feature combination (i.e., in the case of redundancy). In our situation, contextual cuing can be based on neither spatial configuration nor surface-feature combination, but only on their conjunction.

There is significant theoretical value in studying the cuing of feature conjunctions as distinct from their individual effects. As stated above, it should help us understand whether two streams of information (in this case, spatial-configuration and surface-feature information) are represented separately in the unconscious memory, or conjoined as a single entity (the binding problem). From a neural standpoint, surface-feature information (color, object recognition, etc.) is usually carried in the ventral pathway, whereas spatial-configuration information (configuration, motion, etc.) is usually carried in the dorsal pathway. If the unconscious memory reflects “local” learning within ventral or dorsal pathways, then their conjunction should not elicit contextual cuing, despite their individual efficacy. Only if contextual cuing occurs in some different stage should cuing by conjunction be possible. Therefore, identifying cuing by conjunction could shed light on the locus of unconscious memory.

The conjunction of spatial configuration and surface features might take many forms. The form we investigate in the present work is color arrangement: We ask whether the conjunction of location and color can elicit contextual cuing. By the word “color,” we here refer to both chromatic (hue) and achromatic (luminance) components.

METHOD

Subjects

Undergraduates from the University of California, San Diego, received credit in a psychology course for their participation in this project. They ranged in age from 18 to their mid-20s. There were slightly more female subjects than male subjects. All subjects had normal or corrected-to-normal vision. The subjects were clearly tested on color blindness in Experiment 7. In the other experiments, reporting no color blindness was one prerequisite of subjects' participation.

Apparatus

Stimuli were presented on 1,024 × 768 color monitors. There were three such monitors, and each subject was randomly assigned to one of them. The subjects viewed the displays from a distance of about 60 cm and entered responses using the keyboard. The program was written in Microsoft Visual Basic 6.0, and was run in Microsoft Windows 98, second edition.

Stimuli

As shown in Figure 1, each search display contained 16 items: 1 target (T), and 15 distractors (L), both letters consisting of two

Figure 1. A display in Experiment 1. Subjects searched for the T (pointing left or right) in each display. The 16 items of each display were presented in a 4 × 4 array. Here, context was defined as spatial arrangement of object colors. We used eight colors in this experiment (red, green, blue, white, black, yellow, magenta, and cyan), randomly selecting four of these colors to use in each trial (red, blue, white, and cyan, in the present trial). See text for details.

line segments 0.644 cm (0.615°) long × 0.14 cm (0.13°) wide. They were presented in a 4 × 4 array. The distance between centers of neighboring items was 1.41 cm (1.34°). The arrays were framed in a gray region 11.4 cm × 11.4 cm (10.9° × 10.9°), centered on the screen. The remainder of the screen was black. The colors of the stimuli are given below for each experiment.

The target (T) was oriented with its trunk pointing either left or right, and the subjects were asked to respond to this orientation (except in the test blocks of Experiments 5 and 6, as explained below). Distractors (L) had any of four possible orientations.

Procedure

The subjects were asked to respond as accurately and quickly as possible (except in the test blocks of Experiments 5 and 6). Each trial began with a small white fixation cross presented for 400 msec in the center of the screen. After a short blank interval (400 msec), the display appeared. The subjects were instructed to fixate the cross and then to search for the T in each display. The displays remained until the subjects responded. They decided whether the target (T) was pointing left or right, and responded by pressing one of two adjacent keys with the fingers of their right hand (J for left; K for right). A tone sounded to indicate whether the response was correct or not, and the next trial began 400 msec later.

Each subject performed 24 blocks of 24 trials each. In the first block of the experiment, all displays were equally unfamiliar to the subject. But in the following blocks, only 12 of the trials used unfamiliar displays, whereas 12 used old displays repeated from the first block. In old displays, the color of the item in each position was preserved as it had appeared in previous blocks; the location of the target was also preserved. In new displays, these two properties (target location and colors of items) were randomly assigned. Each subject had a different, randomly generated selection of possible stimuli. The orientations of all items (targets and distractors) were assigned randomly in both old displays and new displays.

EXPERIMENT 1

Experiment 1 tested whether color arrangement can produce contextual cuing. As we have described in the General Method section, the 16 items of each display were presented in a 4×4 array. We used eight colors in this experiment (red, green, blue, white, black, yellow, magenta, and cyan), randomly selecting four of these colors to use in each trial. The eight colors were equally likely in this selection, and the four chosen colors were equally likely in their assignment to each item. The color assignment of each item was independent from the others. Each block (except the first) consisted of 12 new trials and 12 old trials. In each new trial, colors were reassigned as described; old trials preserved the color settings of trials in previous blocks. If the unconscious memory ignores color arrangement and encodes only the spatial configuration defined by objects' locations, we would expect no context cuing here. Thirty-four subjects participated in this experiment.

Results

The results of Experiment 1 are given in Figure 2. We evenly divided the 24 blocks into 8 epochs (3 blocks each). There was no systematic difference between old displays and new displays in the first epoch, but in later epochs, subjects did significantly better on old displays than on new ones. We conducted a two-way ANOVA on the average RTs of Epochs 1 and 8 to compare the context cuing effect before learning (Epoch 1) and after learning (Epoch 8) (display type, old vs. new; learning condition, Epoch 1 vs. Epoch 8). This test had been conventionally used in literature of context cuing (Chun & Jiang, 1998). The main effect of display type was significant [$F(1,33) = 13.60, p < .002$]. The main effect of epoch number was significant [$F(1,33) = 86.83, p < .0001$]. The interaction between display type and epoch number was significant [$F(1,33) = 17.13, p < .0003$].

Figure 2. Experiment 1 results. Performance on both old and new displays improves over the course of the experiment, but old displays gradually develop an advantage over new displays. This suggests contextual cuing for color arrangement.

Table 1
Error Rates of Experiments 1–8

	Old Display	New Display
Experiment 1	1.1%	1.2%
Experiment 2	2.0%	2.4%
Experiment 3	1.8%	2.0%
Experiment 4	1.8%	1.9%
Experiment 5	1.6%	1.5%
Experiment 6	1.2%	1.3%
Experiment 7	1.9%	1.8%
Experiment 8	1.4%	1.5%

Note—We have excluded Block 1 in these analyses as practice. In all of the experiments, the error rates are consistently low and show no significant difference between old and new displays.

The error rates of Experiment 1, and of all other experiments, are given in Table 1. We exclude Block 1 as practice when computing error rates. The error rates were always very low and do not indicate any significant patterns. Therefore, we will ignore them in further analysis.

The results of Experiment 1 clearly indicate that color arrangement information can influence contextual cuing. We can therefore reject the extreme hypothesis that the encoding of context involves only spatial configuration defined by object location, not color arrangement.

EXPERIMENT 2

Experiment 1 demonstrates that color arrangement participates in contextual cuing. But it leaves the nature of that participation uncertain. The hypothesis we intend to test posits a *color arrangement representation* (CAR), by which the unconscious long-term memory stores the conjunction of colors and locations. An alternative hypothesis holds that the memory stores not colors themselves, but only the *spatial configuration of color patches* (SCCP); color would participate in the encoding but be ignored in the memory of context. Here, a “patch” means all items of the same color in a display, but it makes no difference for our purpose whether patches are in fact organized otherwise (e.g., if only adjacent same-color items constitute a “patch”). If we suppose a memory system equipped to store spatial configurations but not color arrangement, the SCCP account would represent a reasonable substitutional strategy for handling the kind of displays we presented in Experiment 1. We designed Experiments 2 and 3 to adjudicate between the CAR and SCCP accounts.

In Experiment 2, we eliminated the possibility of an SCCP strategy by introducing more variation in color. The color of each item varied randomly in all three dimensions of R(ed), G(reen), and B(lue) (0–255 gun value in each), with the constraint that at least one of the RGB values was significantly different from the background (<64 or >192 , whereas the background values were all 128) so that every item was clearly visible. Since none of the objects shared the same color, they would be less likely to be grouped by color and form gestalt configurations. Therefore, clearly defined patches (such as those that appeared in Experiment 1) would not be available for

a spatial configuration mechanism to encode. All items appeared to be separate from each other, instead of forming a few patches. If the contextual cuing we found in Experiment 1 relied only on the spatial configuration of color patches, it should not occur in Experiment 2. Thirty-nine subjects participated in this experiment.

Results

The results of Experiment 2 are given in Figure 3. There is a systematic contextual cuing effect.

As above, we conducted a two-way ANOVA on display type and epoch number (Epochs 1 and 8): The main effect of display type (old/new) was significant [$F(1,38) = 18.72, p < .001$]. The main effect of epoch number was significant [$F(1,38) = 210.37, p < .0001$]. The interaction between display type and epoch number was significant [$F(1,38) = 15.96, p < .0003$].

This result argues for the CAR account of contextual cuing and against the SCCP account.

EXPERIMENT 3

We designed Experiment 3 to differentiate CAR and SCCP in another way. The method was identical to Experiment 1, with one exception: Each time an old display was presented, only its spatial configuration was preserved. Patches of uniform color were preserved, whereas the colors themselves were randomly rechosen. Every element that had been a certain color (e.g., red) in one array of a preceding block was switched to the same new random color (e.g., yellow) in the present block's corresponding array. According to the SCCP account (that contextual cuing encodes only the spatial configuration of color patches), this variation should not impair context-

Figure 3. Experiment 2 results. In Experiment 2, we introduced more variation in color to test the alternative hypothesis, which holds that the memory stores not colors themselves, but only the spatial configuration of color patches. In Experiment 2, clearly defined patches (such as those that appeared in Experiment 1) would not be available for a spatial configuration mechanism to encode. There was a systematic contextual cuing effect, arguing against the alternative hypothesis. See text for details.

tual cuing, since spatial configuration is preserved. The CAR account, contrarily, predicts that this reassignment of colors should disable the contextual cuing. Thirty-nine subjects participated in this experiment.

Results

The results of Experiment 3 are given in Figure 4. There is little systematic contextual cuing. As above, we conducted a two-way ANOVA on display type and epoch number (Epochs 1 and 8): The main effect of display type (old/new) was not significant [$F(1,38) = 0.17$]. The main effect of epoch number was significant [$F(1,38) = 148.43, p < .0001$]. The interaction between display type and epoch number was not significant [$F(1,38) = 0.739$].

A three-way across-subjects ANOVA indicates that contextual cuing in Experiment 3 was significantly less than that in Experiment 2 [three-way interaction of display type, epoch number, and experiment: $F(1,76) = 5.33, p < .03$]. Again, this argues for the CAR account and against the SCCP account.

This result may seem to contradict Chun and Jiang's (1998) discovery of spatial-configuration contextual cuing, but in fact, we are addressing different questions. The configuration Chun and Jiang (1998) address is the location of all objects, which is undoubtedly more salient and more pertinent information than spatial configuration defined by color patches.

EXPERIMENT 4

There is still another alternative to the CAR account: that the unconscious memory stores color information but does not associate it with locations. That is to say, the memory of context includes both spatial configuration and color information, but separately. We call this the *presence of color combination* (PCC): The presence of repeated colors triggers the memory of the target location, regardless of whether those colors' locations are also repeated. For example, a display of red, green, and yellow items may be associated with a target in the top-left corner, regardless of how those red, green, and yellow items are spatially distributed. This possibility is similar to the contextual cuing by surface feature found by Chun and Jiang (1999), with one difference: Their cuing associated distractor surface features with target surface features; PCC cuing, on the other hand, associates distractor surface features with target location. In any case, we should address the possible role of PCC in the present study.

In Experiment 4, the same 16 colors were used in all trials, with one item of each color. Thus, the color combination was constant throughout all trials. Under this condition, the PCC account predicts no contextual cuing. The CAR account, on the other hand, predicts significant contextual cuing. Thirty-three subjects participated in this experiment.

Results

The results of Experiment 4 are given in Figure 5. There was significant contextual cuing. As above, we conducted

Figure 4. Experiment 3 results. In Experiment 3, the method was identical to Experiment 1, with one exception: Each time an old display was presented, only its spatial configuration was preserved. Patches of uniform color were preserved, whereas the colors themselves were randomly rechosen. There was no systematic contextual cuing effect, again arguing against the alternative hypothesis of encoding of *spatial configuration of color patches*. See text for details.

a two-way ANOVA on display type and epoch number (Epochs 1 and 8): The main effect of display type (old/new) was significant [$F(1,32) = 13.03, p < .002$]. The main effect of epoch number was significant [$F(1,32) = 118.20, p < .0001$]. The interaction between display type and epoch number was significant [$F(1,32) = 8.92, p < .01$]. This again argues for the CAR account and against the PCC account.

EXPERIMENT 5

One important and unique characteristic of contextual cuing is its unconscious nature (Chun & Jiang, 1998, 2003). In Experiments 5 and 6, we tested whether the color-arrangement-based contextual cuing observed in our Experiments 1–4 is also unconscious. We used two methods that have been used in the past to demonstrate the implicitness of spatial-configuration cuing: testing whether subjects could distinguish between old and new displays (Chun & Jiang, 1998), and whether they could consciously access memory of target locations in old displays (Chun & Jiang, 2003). Because we were testing a negative hypothesis, and because the number of trials in our test blocks was very limited, we ran a much greater number of subjects to increase statistical power.

Experiment 5 was identical to Experiment 4 except that in the last two blocks (“test blocks”) the task was different. The subjects’ task in the test blocks was not to identify the target, but to judge whether they had previously seen the display. They were encouraged to respond as accurately as possible, regardless of speed. Forty-two subjects participated in this experiment.

Results

Blocks 1–22 of both Experiments 5 and 6 were identical to those of Experiment 4. In Experiments 5 and 6, we divided the 22 blocks into seven epochs (the first six contained 3 blocks each and the last epoch contained 4 blocks). The results of these epochs for both experiments are shown together in Figure 6, though we ran statistical tests independently. There was significant contextual cuing in Experiment 5. As above, we conducted a two-way ANOVA on display type and epoch number (Epochs 1 and 7): The main effect of display type (old/new) was nearly significant [$F(1,41) = 3.68, p < .1$]. The main effect of epoch number was significant [$F(1,41) = 103.35, p < .0001$]. The interaction between display type and epoch number was significant [$F(1,41) = 4.28, p < .05$]. This confirms the results of Experiment 4.

Accuracy in the test blocks of Experiment 5 was $50.4\% \pm 2.4\%$. This is not significantly different from the chance level, 50% ($p = .38$), indicating that despite significant contextual cuing, subjects cannot judge explicitly whether they have had previous exposure to a display. This confirms the unconscious nature of the observed color-arrangement-based contextual cuing effect.

EXPERIMENT 6

Experiment 6 was again identical to Experiment 4, except for a change in the task in the last two blocks. In these test blocks, only old displays were used, with the difference that the target was replaced with a randomly generated distractor of the same color. The subjects’ task was to recall the position of the target. Each old display was used twice: once to judge whether the target was in the left

Figure 5. Experiment 4 results. In Experiment 4, we tested the alternative hypothesis, that *presence of color combination* mediated the contextual cuing here. In Experiment 4, the same 16 colors were used in all trials; thus, the color combination was constant throughout all trials. There was a systematic contextual cuing effect, arguing against the alternative hypothesis. See text for details.

Figure 6. Experiment 5 and 6 (Blocks 1–22) results. In Experiments 5 and 6, we tested whether this contextual cuing is implicit. The figure plotted the learning blocks (1–22). See text for discussion on the test blocks.

or right half of the display and once to judge whether it was in the top or bottom half. The left/right judgment and top/bottom judgment were run in two successive trials. The subjects were encouraged to respond as accurately as possible, regardless of speed. Thirty-nine subjects participated in this experiment.

Results

There was significant contextual cuing in Experiment 6. As above, we conducted a two-way ANOVA on display type and epoch number (Epochs 1 and 7): The main effect of display type (old/new) was significant [$F(1,38) = 10.77, p < .003$]. The main effect of epoch number was significant [$F(1,38) = 119.42, p < .0001$]. The interaction between display type and epoch number was significant [$F(1,38) = 5.88, p < .03$]. The accuracy in test blocks was $51.1\% \pm 2.4\%$. This is not significantly different from the chance level, 50% ($p = .18$), indicating that despite significant contextual cuing, subjects have no conscious access to the locations they are cued to.

EXPERIMENT 7

As noted above, we have been using the word “color” to refer to both chromatic (hue) and achromatic (luminance) components. Previous studies have found that luminance and hue play very different roles in some stages of vision and cognition. In motion perception, for example, luminance plays a predominant role, whereas hue signifies very little.

In Experiments 7 and 8, we investigated the respective roles of hue and luminance in contextual cuing. In Experiment 7, we made the background and all items isoluminant, varying only in hue. In Experiment 8, we made the background and all items the same hue (gray), varying only in luminance. Our results thus far (Experiments 1–6) have suggested that contextual cuing is not represented

only discretely in dorsal (spatial, motion, etc.) or ventral (object, surface feature) streams; rather, some kind of conjunction between the two streams is involved. But this notion will be suspicious if contextual cuing in these experiments is mediated exclusively by luminance. Although luminance by itself is a surface feature, unlike hue, it is encoded in the dorsal pathway.

In Experiment 7, six chosen colors were randomly assigned to the 16 items on a gray background, with the constraint that no color was used for more than 3 items. The CIE values (x, y) for the colors were: blue (0.150, 0.069); red (0.605, 0.341); purple (0.277, 0.146); green (0.285, 0.576); cyan (0.209, 0.292); yellow (0.390, 0.498); and for the background, gray (0.277, 0.296). Isoluminance of those colors was adjusted by a flicker fusion test (see details below). Forty subjects participated in this experiment.

Each subject started the flicker fusion test with colors at equal physical intensity (14.5 cd/m^2 , measured by photometer). The stimuli used as flickers were spatially similar to what was used in the experiments (16 items arranged in 4×4 arrays) and were presented at a speed of 25 Hz. The flicker of two colors (randomly chosen from the six) was shown, and the subject adjusted the luminance value until he or she felt the flicker was minimal. Then one new color was randomly chosen and the flicker was created by pairing the new color with each of the old colors. Then another new color was paired with each of the three old colors. This procedure was repeated until the sixth color was equated with the first five. The entire session was repeated 15 times and the averages of these values were used in the following experiment. The results from sessions were fairly consistent.

Results

The results of Experiment 7 are given in Figure 7. There was significant contextual cuing. As above, we conducted a two-way ANOVA on display type and epoch number (Epochs 1 and 8): The main effect of display type

Figure 7. Experiment 7 results. In Experiment 7, we tested the contribution of chromatic component (hue) in contextual cuing. There was a systematic contextual cuing effect. See text for details.

(old/new) was significant [$F(1,39) = 5.46, p < .05$]. The main effect of epoch number was significant [$F(1,39) = 97.03, p < .0001$]. The interaction between display type and epoch number was significant [$F(1,39) = 25.12, p < .00002$].

EXPERIMENT 8

Experiment 8 was identical to Experiment 7, except that Experiment 8 used different luminance levels (instead of different hues) for the background and items: The luminance levels for items were 80 cd/m², 70 cd/m², 60 cd/m², 30 cd/m², 20 cd/m², or 10 cd/m². The background luminance was 45 cd/m². The hue of the background and all items was gray. Thirty-seven subjects participated in this experiment.

Results

The results of Experiment 8 are given in Figure 8. There was significant contextual cuing. As above, we conducted a two-way ANOVA on display type and epoch number (Epochs 1 and 8): The main effect of display type (old/new) was nearly significant [$F(1,36) = 3.07, p < .1$]. The main effect of epoch number was significant [$F(1,36) = 128.60, p < .0001$]. The interaction between display type and epoch number was significant [$F(1,36) = 6.28, p < .02$].

Even though the contextual cuing was significant in both Experiments 7 and 8, the effect of cuing in Experiment 8 was significantly less than that in Experiment 7 (see Figure 9). This is supported by a three-way across-subjects ANOVA [three-way interaction of display type, epoch number, and experiment: $F(1,75) = 6.12, p < .02$]. This result seems to suggest that contextual cuing is more effective on chromatic variation than on achromatic variation. Further studies would be needed to fully address this.

The greater contextual cuing in Experiment 7 (chromatic variation) than in Experiment 8 (achromatic varia-

tion) also helps to establish the conclusion that contextual cuing is not based solely on luminance variation. Even if we tried to control the luminance in Experiment 7, the stimuli might still deviate slightly from absolute isoluminance (e.g., random error in psychophysics measurement, different isoluminance point for fovea and periphery). Therefore, one may still suspect that contextual cuing in Experiment 7 relied on such slight luminance variation. However, such slight luminance variation in Experiment 7 could not possibly be larger than luminance variation in Experiment 8. Therefore, hue variation must be responsible, since we found that contextual cuing was systematically larger in Experiment 7 than in Experiment 8.

DISCUSSION

Our eight experiments indicate that color arrangement representation plays an unconscious role in contextual cuing. This cuing does not rely on the shape of color patches (Experiments 2 and 3), nor is it created by the repetition of color combinations without location repetition (Experiment 4). Subjects can neither distinguish between old and new displays (Experiment 5), nor consciously remember the target locations associated with certain old displays (Experiment 6), indicating that this contextual cuing is unconscious. A color arrangement representation of either only chromatic variation (Experiment 7) or only achromatic variation (Experiment 8) is sufficient to elicit contextual cuing. In summary, this contextual cuing reflects an unconscious representation of color–location conjunction, where color includes both luminance and hue.

What differentiates the present work from the previous finding is that the context that is learned is not based on a configuration consisting of the binary presence or absence of objects in the display at various locations (Chun & Jiang, 1998). Instead, all locations on every trial are filled with objects, and the configuration is defined by the colors of the objects. On the other hand, the context that is learned is not based on the presence of certain feature combinations (Chun & Jiang, 1999). This finding gives an important insight into the basic algorithm adapted by unconscious memory: Spatial-configuration and surface-feature processing, which are separated in many stages of conscious visual processing, are processed integratively in the unconscious memory. This stands in contrast with the “binding problem” in visual attention and visual working memory (Green, 1991; Treisman & Gelade, 1980; Wolfe & Cave, 1999). From a computational point of view, encoding, storing, and processing color arrangements is much more challenging than encoding, storing, and processing spatial configurations and surface features separately, especially considering the number of displays that must be stored and chosen from. It would be illuminating to know how the brain overcomes this computational difficulty. Further tests on the limits of the contextual cuing of color arrangement will help determine whether the brain uses any approximation, and if so, its nature.

As for the neural basis of contextual cuing, our findings suggest that cuing does not function only separately

Figure 8. Experiment 8 results. In Experiment 8, we tested the contribution of achromatic component (luminance) in contextual cuing. There was a systematic contextual cuing effect. See text for details.

Figure 9. Comparison between contextual cuing of Experiments 7 and 8. The cuing is systematically larger in Experiment 7 (hue variation) than in Experiment 8 (luminance variation). See text for details.

through ventral and dorsal pathways; such a separated mechanism cannot explain color arrangement representation. The underlying mechanism must involve some different level of processing.

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NOTE

1. There is a subsequent report on conscious recognition of old displays (Peterson & Kramer, 2001). However, the degree of recognition is uncorrelated with the degree of contextual cuing. Therefore, the report confirms, rather than refutes, the implicit nature of contextual cuing.

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