Effects of spatial configurations on visual change detection: An account of bias changes

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In order to determine whether people encode spatial configuration information when encoding visual displays, in four experiments, we investigated whether changes in task-irrelevant spatial configuration information would influence color change detection accuracy. In a change detection task, when objects in the test display were presented in new random locations, rather than identical or different locations preserving the overall configuration, participants were more likely to report that the colors had changed. This consistent bias across four experiments suggested that people encode task-irrelevant spatial configuration along with object information. Experiment 4 also demonstrated that only a low-false-alarm group of participants effectively bound spatial configuration information to object information, suggesting that these types of binding processes are open to strategic influences.

In the last decade, the visual change detection paradigm has been widely used to investigate visuospatial working memory (e.g., Alvarez & Cavanagh, 2004; Awh, Barton, & Vogel, 2007; Jiang, Olson, & Chun, 2000; Luck & Vogel, 1997; Zhang & Luck, 2008). In visual change detection, individuals are asked to encode and remember a set of stimuli and then compare this set with a second set of stimuli and identify changes in object identities, their features, or their locations. Previous research has shown that task-irrelevant changes influence the likelihood of detecting task-relevant changes. This has been attributed to the fact that task-irrelevant information is sometimes maintained in short-term memory along with task-critical information. By looking at the effects of task-irrelevant spatial configuration changes on color change detection accuracy, we investigated whether and under which conditions spatial configuration information is maintained in visual short-term memory.

Recently Hyun and his colleagues have proposed a comprehensive model of visual change detection (Hyun, Woodman, Vogel, Hollingworth, & Luck, 2009). According to Hyun et al., viewers in a visual change detection task first encode the initial stimulus display. Then viewers form stable working memory representations from these early, relatively unstable perceptual representations. These representations are maintained during a retention interval. Then, when the second display is presented, viewers

initially determine the correspondences between the two displays. That is, they identify which object from the first display should be compared with which object from the second display. Once correspondences are established, the viewer then detects whether a change is present. This is achieved via an unlimited-capacity system; thus, it is a relatively easy task. However, at this stage, the nature of the change is not yet identified. During a subsequent verification stage, the identity of the change is determined by a limited-capacity system. Once the change is identified, the appropriate decision rule is activated and the proper response is carried out (e.g., a keypress indicating a color change). Hyun et al. presented both behavioral and electrophysiological data to support the dissociation of the change detection and verification stages.

According to this model, erroneous *change* responses can occur with failures at the verification phase. Specifically, Hyun et al. (2009) showed that when there was only a task-irrelevant visual feature change, there was approximately a 10% increase in the proportion of *change* responses, suggesting that people had mistaken a task-irrelevant change for a task-critical one. On the basis of this finding, Hyun et al. concluded that “the irrelevant dimension was clearly encoded . . . even though it was maladaptive to do so” (p. 1154). Hyun and his colleagues explained that people can detect task-irrelevant feature changes and that these task-irrelevant changes can mis-

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guide viewers to give a *change* response when the exact identity of the change is not determined in the verification stage (Hyun et al., 2009).

Our research utilized the impact of task-irrelevant changes on judgments of task-relevant ones to determine whether spatial configuration information is encoded and maintained while people process object information. Simons (1996) claimed that spatial configurations are easily maintained in visuospatial working memory, on the basis of demonstrations that, in a visual change detection task, viewers detected changes in the configurations formed by to-be-remembered objects with greater ease (and almost always accurately), as compared with changes in the object–location bindings (i.e., location swaps of two studied objects) and in the objects themselves. He concluded that information about spatial layouts, as opposed to information about the visual properties of objects, did not “depend on effortful abstraction” (Simons, 1996, p. 305).

More recently, research has specifically documented that relative location information is bound to object feature information, such as the color of objects (e.g., Jiang et al., 2000; Olson & Marshuetz, 2005; Olson et al., 2004). For instance, Olson and Marshuetz presented participants with a single complex target, such as a face, in a display including other, nonmemory items. After a brief delay period, another complex item was presented, and viewers were asked whether this item was identical to the target. When the location of the target was maintained, relative to other, nonmemory items in the display, judgments were significantly faster than when the target was randomly displaced. Olson and Marshuetz concluded that the relative location of a complex object was included within its representation.

Jiang et al. (2000) argued for the inclusion of relative location information not only when single complex targets are maintained, but also when multiple objects are to be stored in visual short-term memory. They found that color change detection accuracy was equally high when a set of target objects were presented in identical locations (the *same* condition) and when they occupied corresponding locations expanded out to preserve the original spatial configuration (the *expand* condition). Furthermore, color change detection accuracy in these two conditions was significantly higher than when the objects were randomly displaced in the second display (the *random* condition). This pattern of results will be referred to as the *configuration effect* hereafter. On the basis of this evidence, Jiang and colleagues argued that objects are maintained in visual short-term memory in a configural fashion.

Jiang et al.'s (2000) major conclusion was based on the comparison of color change detection performance between expanded displays that maintained configuration information and displays that presented the to-be-remembered objects randomly. It is possible that the effect reported as a *configuration effect* by Jiang et al. could be an *expansion* effect. That is, people could be better in the *expand* condition because of other factor(s) besides accurate maintenance of configurations. Given the theoretical importance of the Jiang et al. findings, it is crucial that the results be replicated in another condition in which

configurations are maintained but exact locations are not. In Experiment 1, we directly tested this with a *shrink* condition in which we shrank the configuration formed by the items in the studied display in the test phase.

One alternate explanation of the configuration effect in Jiang et al. (2000) may have to do with how viewers establish correspondences in the test phase. When objects are not in identical or highly predictable locations in the test display, viewers need to search the test display to determine which object from the study display corresponds to which object from the test display. This search process is known to interfere with the maintenance of an object and results in a drop in visual change detection performance (Fencsik, 2003). It is possible that in Jiang et al.'s data, what has been interpreted as a configuration effect may, in fact, be a boost of performance in the *expand* condition resulting from individuals' starting a search phase in relatively outer portions of the test display. If individuals initially search outer portions of the test display, they will resolve the correspondence problem much faster in the *expand* condition than in the *random* condition. Thus, there may be greater decay in the *random* condition, resulting in poorer visual change detection accuracy. Recently, in a study investigating cross-cultural differences in allocation of attention in content-free visual displays, we indeed have shown that there are individual differences in where viewers start searching for a change in the test display. The data suggested that differences in where attention was allocated in the test display influenced visual change detection accuracy across conditions (Boduroglu, Shah, & Nisbett, 2009).

EXPERIMENT 1

To rule out the possibility that the configuration effect is at least partly determined by the ease with which correspondences are established in the *expand* condition, and also to determine whether the configuration effect reported by Jiang et al. (2000) was not really just an expansion effect, we employed a slight variant of their paradigm. Specifically, in Experiment 1, we compared how overall accuracy and response biases changed across four conditions: *same*, *expand*, *shrink*, and *random*. If the effect reported by Jiang et al. were due to viewers' organizing items in visual short-term memory in a configural manner, we would expect people to show similar levels of accuracy on all trials where configurations are maintained between the study and test displays. In other words, visual change detection accuracy would be approximately equal in the *same*, *shrink*, and *expand* conditions and significantly higher than in the *random* condition. The Hyun et al. (2009) model allows us to make another, related prediction. If people maintained configuration information, changes in this task-irrelevant dimension might impact the likelihood of reporting color changes. According to the Hyun et al. model, then, if spatial configuration information was encoded along with object features, changes in this task-irrelevant domain would increase the likelihood of people's reporting a color change even in the absence of one. Thus, the likelihood of reporting a color change

would be higher when there were no color changes but there were task-irrelevant spatial configuration changes (as in the *random* condition, as opposed to the *same*, *expand*, and *shrink* conditions).

Method

Participants. Twenty-one undergraduates with normal or corrected-to-normal vision participated in the experiment. None reported being color-blind. Data from 1 participant were dropped because overall accuracy was more than two standard deviations from the group mean. All the participants provided informed consent and were debriefed.

Materials and Procedure. On each trial, two images consisting of four colored squares were presented on a gray background, separated by a delay interval. A dim gray cross (18×18 cm) was always presented at the center of the display to serve as a reference point. Objects appeared within an invisible square (sides = 8 cm). Each colored square (0.8×0.8 cm) was one of eight colors (red, green, blue, purple, cyan, yellow, magenta, or white). In a particular display, the repetition of colors was not allowed, and when color changes were introduced, one of the colored boxes changed color to one of the remaining colors from the original set of eight. The participants initiated each trial by pressing the space bar after getting a prompt asking whether they were ready. Each trial started with a black fixation cross (0.5×0.5 cm) that remained on the screen for 507 msec. The participants were instructed to keep their eyes on the fixation cross while it was visible. Then the initial display screen was presented for 150 msec. After a blank interval of 907 msec with the gray background, the second visual display was presented until the participants responded. Figure 1 depicts a color change detection trial. Following incorrect responses, sound feedback was provided. This procedure was similar to that used in Jiang et al. (2000, Experiment 3A), but we shortened the encoding time from 400 to 150 msec and included an extra *shrink* condition and catch trials.

In Experiment 1, a quarter of the trials were the *same-location* trials, and items were located in exactly the same locations across the first and second displays. In the remaining, *different-location* trials,

the locations of the objects changed in the second display. A third of these trials were *expand*, another third were *shrink*, and the rest were *random* trials. On the *expand* and *shrink* trials, the configuration formed by the objects in the initial screen was preserved in the second screen; on the *random* trials, the configurations across the first and second screens did not match.

To determine the locations of the colored squares, we first randomly generated sets of four locations (one per quadrant). These locations were the locations the colored squares occupied in the initial display. In the *same* condition, the objects occupied identical locations in both displays. To determine where objects would shift to in the *expand* condition, a subset of initial locations were expanded out by a fixed factor (1.7); these locations were along the same vector (starting at the origin) as the locations in the first display, but were placed outward. For the *shrink* trials, the locations were generated similarly to how they were generated for the *expand* trials, but in the *shrink* condition, the order of presentation was reversed, so that the initial display was farther out than the second display.

For the *random* condition, to determine where the objects would shift in the second display, another set of four locations (per trial) were randomly generated, with the only constraint being that there would be one location per quadrant. Then we selected a subset of these “random” locations such that the average amount of displacement between the original and the corresponding (i.e., occupying the same quadrant) random locations across all trials was identical to the average amount of displacement between the original locations and the corresponding expanded locations. Also, on half of the *random* trials, objects were placed in the “random” locations in the first display and then they were moved to their “original” locations. Thus, on half of the *random* trials, the displacement was from the periphery to more central locations and, on the rest, it was from more central to more peripheral locations. This ensured that the *direction* of displacement on the *expand* and *shrink* trials was matched to the direction of displacement on the *random* trials.

There were also catch trials to ensure that people were focusing on the center and not moving their eyes throughout the encoding session. During the catch trials, the black fixation cross turned into a small square appearing right at the center of the screen. The partici-

Figure 1. The visual color change detection task. After the initial display, following the delay interval, objects are presented in the same locations, in expanded-out or shrunken-in locations, or in random locations, with the only constraint being that there is a single item in each quadrant.

Figure 2. Proportions of accuracy across the *same*, *expand*, *random*, and *shrink* conditions for color-change and no-color-change trials in Experiment 1. Error bars represent the standard errors of the means.

participants were asked to do a keypress immediately following the detection of the square. If it took them longer than 500 msec to respond to the square, they received a reminder saying, "Please keep eyes on the plus sign." However, the participants were told that this reminder would appear randomly.

All the trials were randomly intermixed. During the practice phase, the participants performed 16 change detection and 4 catch trials, and during the data collection phase, they completed 120 experimental and 24 catch trials. There was an equal number of trials in the *same*, *expand*, *shrink*, and *random* conditions. Color changes occurred on half of the trials, were equally distributed across the four conditions, and occurred equally frequently at each quadrant.

Apparatus. The experiment was programmed using E-Prime software (Psychology Software Tools, Inc.), and the stimuli were presented on 17-in. Dell monitors. The participants were seated approximately 57 cm from the monitor, at which distance 1 cm corresponds approximately to 1° of visual angle.

Data analysis. Since we were interested in how color change detection accuracy and bias to respond *change* is different across the four conditions in which location is manipulated, we calculated accuracy for color-change (change) and no-color-change (no-change) trials separately for each condition. We also computed parametric estimates of sensitivity (d') and bias (c). The sensitivity measure, d' , ranges from zero to infinity (but practically, performance is considered at ceiling if d' exceeds 4.65). To calculate d' scores for all the participants, throughout the article, all hit rate proportions that were 1 were lowered to .99, and all false alarm rate proportions that were 0 were increased to .01. As for the bias scores, negative values for c indicate a *yes* bias, and positive values indicate a *no* bias, with the neutral point being zero.

Results

Figure 2 displays proportions of accuracy across the color change and no-color-change trials for the four conditions.

A 2×4 repeated measures ANOVA, with type of trial (change, no change) and condition (*same*, *expand*, *shrink*, *random*) was run. The analysis yielded a significant main effect of type of trial [$F(1,19) = 5.57$, $MS_e = 0.037$, $p <$

.03, $\eta_p^2 = .23$]; accuracy on color-change trials ($M = 82.5 \pm 1.70$) was significantly lower than accuracy on no-color-change trials ($M = 89.6 \pm 2.20$). There was also a main effect of condition [$F(3,57) = 12.82$, $MS_e = 0.006$, $p < .001$, $\eta_p^2 = .40$]. A visual inspection of the data suggested that accuracy was lower in the *expand* and *shrink* conditions than in the remaining conditions. A contrast comparing accuracy in the *expand* and *shrink* conditions with accuracy in the *same* and *random* conditions confirmed that the main effect was due to these differences [$t(19) = -6.06$, $p = .000$]. These main effects were qualified by a significant interaction [$F(3,57) = 3.04$, $MS_e = 0.007$, $p < .04$, $\eta_p^2 = .14$]. Specifically, for all configurally congruent conditions (*same*, *expand*, and *shrink*), accuracy was significantly higher when there was no color change than when there was one, but this pattern was not replicated in the *random* condition ($t < 1$). Although this specific contrast was significant for the *same* trials [$t(19) = -4.21$, $p = .000$] and *expand* trials [$t(19) = -2.57$, $p = .008$], it was only marginally significant for the *shrink* trials [$t(19) = -1.49$, $p = .07$, one-tailed].

As can be seen from Table 1, d' scores were in line with the accuracy measures. Sensitivity was significantly lower in the *expand* and *shrink* conditions than in the *same* condition. The bias measure c indicates that individuals were biased to report no color changes when the objects were in the *same*, *expanded*, or *shrunk* locations (all maintaining the same configuration) and not in the *random* condition. This finding was consistent with the observation drawn from the accuracy data: In the *random* condition, accuracy was similar for the change and no-change trials.

In the reaction time (RT) data, there was an advantage for the *same*-location trials. When locations of the objects remained the same, responses were faster ($M = 851.45 \pm 50.82$) than in the other conditions ($M_s = 912.60 \pm 48.43$, 906.53 ± 55.98 , and 941.13 ± 58.30 for the *expand*, *shrink*, and *random* conditions, respectively) [$t(19) > 3.30$ for all pairwise comparisons].

Discussion

In Experiment 1, there was a greater proportion of *change* responses in the *random* condition than in the configurally congruent conditions (*same*, *expand*, and *shrink*). The fact that task-irrelevant configural changes

Table 1
Mean Sensitivity and Bias Estimates for Experiment 1

Condition	d'	c
Same	2.82	0.27*
Expand	1.98	0.27*
Shrink	2.30	0.18*
Random	2.79	-0.11

Note—A repeated measures ANOVA on d' yielded a main effect of condition [$F(3,57) = 9.09$, $MS_e = 0.358$, $p < .001$, $\eta_p^2 = .324$]. Pairwise comparisons revealed that sensitivity was significantly lower in the *expand* and *shrink* conditions than in the *same* condition; it was also significantly lower in the *expand* than in the *random* condition. For bias scores, using single-sample t tests, we tested whether the average values of c were significantly different from the criterion set at the no-bias value, 0. * $p < .05$.

increased the likelihood that the viewers would report a color change suggests that configural information is maintained in visual short-term memory. These findings are consistent with the predictions drawn from the visual change detection model proposed by Hyun et al. (2009).

Another major finding was the variation in accuracy across the four conditions. Interestingly, the pattern observed did not replicate the pattern Jiang et al. (2000) reported for accuracy.¹ Whereas they reported significantly higher performance in configurally congruent conditions (*same* and *expand*) than in the *random* condition, in the present experiment, accuracy was lowest in the *expand* condition and highest in the *same*- and *random*-location conditions, with accuracy being in the middle for the *shrink* condition. The reason for lower levels of accuracy in the *expand* condition, as compared with the *same*-location condition, may be strategic. On more than half the trials, the objects either appeared in exactly the same location or moved to locations closer to the center of the screen. If the participants had implicitly noticed this, they might have developed an expectancy that, after the initial display, the objects would appear within a region whose outside boundary was determined by the first display. Consequently, they may have directed their attention around that region. When the objects appeared in expanded locations, this might have required them to refocus their attention to a broader region and encode the new objects. This extra time to refocus and encode the objects might have interfered with the maintenance process, and the object representations might have partially decayed, impairing their performance. These findings indicate how participants' search strategies in establishing correspondences may be partially influenced by their implicit knowledge of where objects typically appear. In other words, where people start searching the visual display to establish correspondences is open to strategic influences.

The RT data did not suggest that the accuracy pattern observed was driven by a speed–accuracy trade-off. Most important, in the *same* condition, RT was significantly shorter than in the other conditions. This may be due to an advantage in establishing correspondences between the memory and test displays when objects are in identical locations; this is consistent with Fencsik's (2003) model. In addition, the *fast–same* effect on overall *same*-location RT may have contributed to the RT advantage observed in the *same* condition. The *fast–same* effect refers to how people are much faster at identifying two consecutive displays as identical than at identifying them as different (for a review, see Farell, 1985). In the *same*-location condition, half of the trials did not include any color changes (no-change trials); thus, on a subset of the *same* trials, the study and test displays were identical. Therefore, people may have been responding much faster on this subset of the *same*-location trials, reducing the average RT for the *same* condition, relative to the other conditions.

EXPERIMENT 2

In Experiment 2, we further investigated the effects of task-irrelevant spatial configuration changes on color

change detection. The goal was to establish whether configuration information impacts change detection performance even when the task demands highlight the irrelevance of configuration information. In the previous experiment, the different conditions were intermixed, possibly allowing sudden spatial configuration changes to capture attention. In this experiment, we blocked different conditions together, hoping that this would allow the viewers to more easily identify spatial configuration information as task irrelevant and disregard it. Thus, when trials are blocked, spatial configuration changes may have no effect on response bias. However, another pattern of results is also plausible. If spatial configuration information is bound to object information effortlessly and, perhaps, even unavoidably, even blocking trials by condition may not be sufficient for spatial configuration information to be tagged as task irrelevant. If so, we would expect to see a pattern of results similar to those obtained in Experiment 1: an increase in the rate of *change* responses when colors remain identical but spatial configurations change.

Method

Participants. Twenty-four undergraduates with normal or corrected-to-normal vision participated in the experiment. None reported being color-blind. The participants were randomly assigned to one of three groups, which determined the order in which they would be receiving each block. All provided informed consent and were debriefed.

Materials and Procedure. All the parameters were kept identical to those in Experiment 1, except that, in Experiment 2, there were three blocked conditions: *same*, *expand*, and *random*. We excluded the *shrink* condition from this experiment because of the similarity of the overall accuracy levels for the *expand* and *shrink* conditions in Experiment 1. The participants were randomly assigned to one of three orders of presentation for the blocks: *same*, *expand*, *random*; *expand*, *random*, *same*; or *random*, *same*, *expand*. Also, since the trials were blocked, instead of completing 24 mixed practice and 6 catch trials at the beginning of the experiment, in this experiment, the participants completed block-specific practice prior to each block. Each practice block had 8 practice and 2 catch trials. Half of the practice trials had color changes.

Results

In order to determine whether there were any effects of order of presentation on performance, performance was compared across the three versions. Since there were no differences across the three groups [$F(2,21) = 1.09$, $MS_e = 26.143$, $p = .354$], the data were combined for the rest of the analyses. Figure 3 presents average accuracy for the three conditions for color-change and no-color-change trials.

To determine whether performance varied across conditions as a function of the presence of a color change, a 2×3 ANOVA with type of trial (change, no change) and condition (*same*, *expand*, *random*) as the repeated factors was conducted. As in the previous experiment, accuracy on color-change trials ($M = 80.1 \pm 2.5$) was significantly lower than accuracy on no-color-change trials ($M = 89.9 \pm 1.4$) [$F(1,23) = 14.32$, $MS_e = 0.024$, $p = .001$, $\eta_p^2 = .38$]. There was a small but significant main effect of condition [$F(2,46) = 3.48$, $MS_e = 0.006$, $p = .04$, $\eta_p^2 = .13$]. As can

Figure 3. Data from Experiment 2: Proportions of accuracy when trials from *same*, *expand*, and *random* conditions were blocked. Data are shown separately for color-change and no-color-change trials. Error bars represent the standard errors of the means.

be seen in Figure 3, and as post hoc pairwise comparisons confirmed, the main effect was due to the significantly higher accuracy in the *same*-location condition than in the *expand* and *random* conditions [$t(23) = 2.19, p < .039$, and $t(23) = 2.44, p < .023$, respectively]. These findings were also replicated when d' was the dependent measure; performance was higher in the *same* condition than in the *random* condition. However, performance was not higher in the *expand* condition than in the *random* condition (see Table 2). The main effect of condition did not seem to stem from an RT–accuracy trade-off; the main effect of condition on RT was not significant ($F < 1$).

The two main effects were qualified by a significant interaction between type of trial and condition [$F(2,46) = 6.81, MS_e = 0.007, p = .003, \eta_p^2 = .23$]. Post hoc comparisons revealed that type of trial had an impact in all but the *random* condition ($t < 1$). Simple t tests comparing performance on the configurally congruent trials indicated that accuracy was higher on no-color-change trials [$t(23) = 3.50, p = .002$, and $t(23) = 4.81, p < .000$, for the *same* and *expand* conditions, respectively]. This suggested that in these conditions, the *no* bias was more pronounced. However, equal levels of change and no-change responses in the *random* condition suggested that people were more likely to report a color change when, in reality, there was only a configuration change. In other words, there was a greater proportion of *change* responses in the *random* condition than in the *same* and *expand* conditions. Bias estimates presented in Table 2 corroborate that the bias to respond *change* was stronger when configurations were disrupted. When configurations were preserved in both the *same* and *expand* conditions, c values significantly differed from the neutral, no-bias point.

Discussion

In Experiment 2, we found further evidence that spatial configuration information is encoded as visual object features are processed. As in Experiment 1, we observed that task-irrelevant spatial configuration changes (in the *random* condition) increased the likelihood that the viewers would report color changes even when there were no color changes; this was the case even when these task-irrelevant spatial configuration changes were grouped together to highlight their task-irrelevant nature. As in Experiment 1, these findings are in accordance with the predictions drawn from the Hyun et al. (2009) model.

Overall, accuracy levels across the three conditions did not replicate the pattern of results obtained by Jiang et al. (2000). Even though performance was slightly better in the *same*-location condition (only when percentage of accuracy was considered), performance was equally lower in the *expand* and *random* conditions. One of the reasons as to why we may not have been able to replicate the pattern of findings reported by Jiang et al. on accuracy may have to do with the procedural differences between the studies. Specifically, in Experiment 1, we had four conditions rather than three, and in Experiment 2, we used a blocked design. Furthermore, we used a shorter (150-msec) encoding time, as compared with Jiang et al., who presented displays for 400 msec. Therefore, in Experiment 3, we tried to match our parameters to those reported by Jiang et al. and investigated whether we still would get the bias effects that we consistently observed in the first two experiments. We also investigated whether we would be able to replicate the configuration effect reported by Jiang et al. when we procedurally replicated them.

EXPERIMENT 3

In Experiment 3, we followed the design of Experiment 3A in Jiang et al. (2000). Specifically, we had three conditions—*same*, *expand*, and *random*—and trials were presented in mixed order. Therefore, we procedurally replicated the paradigm employed by Jiang et al. In a separate between-subjects condition, we also manipulated encoding time to examine the effects of possible eye movement patterns on how easily and how well configuration information is maintained. It is possible that when displays are

Table 2
Mean Sensitivity and Bias Estimates for Experiment 2

Condition	d'	c
Same	2.61	0.23*
Expand	2.40	0.35*
Random	2.17	0.13

Note—A comparison of conditions on sensitivity yielded a small main effect of condition [$F(2,46) = 4.03, MS_e = 0.29, p < .024, \eta_p^2 = .149$], driven by significantly lower scores in the *random* condition than in the *same* condition. However, unlike in Jiang, Olson, and Chun (2000), performance in the *expand* condition was not significantly higher than that in the *random* condition. Bias values c were tested against the no-bias criterion, 0; significant deviations from this critical value are indicated. * $p < .05$.

presented very briefly, viewers either can extract information about the overall configuration or can focus only on task-critical object information and disregard spatial configuration information. On the other hand, when displays are presented for longer durations, allowing viewers to make eye movements between target objects, information about the spatial relationships between objects may be encoded better. This may help people maintain the global configuration of objects. To investigate how encoding time impacts response bias and color change detection accuracy, we chose to present displays for either 400 or 150 msec. Jiang et al. had used 400 msec to present the displays in the experiment cited, and 150 msec is too short of a period for eye movements to be programmed and executed (Kowler, 1995). In addition, many other visual change detection studies have used 100 to 150-msec encoding durations with simple objects (e.g., Luck & Vogel, 1997; Wheeler & Treisman, 2002). Variations in encoding time have been shown not to impact overall visual change detection accuracy (e.g., Alvarez & Cavanagh, 2004; Luck & Vogel, 1997), except for when the complexity of the study items was increased (e.g., Eng, Chen, & Jiang, 2005). Even though it is unlikely that encoding time was the reason for our inability to replicate Jiang et al., we nevertheless wanted to test this possibility directly.

Method

Participants. Twenty-one undergraduates with normal or corrected-to-normal vision participated in the experiment. None of them reported being color-blind. Eleven of them were assigned to the 400-msec encoding duration, and the rest were assigned to the 150-msec encoding duration. Data from 2 participants for the 400-msec duration and 1 for the 150-msec duration were dropped because their overall accuracy was more than two standard deviations below each group mean, leaving us with 9 participants at both encoding durations. All the participants provided informed consent and were debriefed.

Materials and Procedure. All the parameters were identical to those in Experiment 2, except for two factors: (1) Encoding time was manipulated, and (2) all the trials were randomly intermixed. During the practice phase, the participants performed 16 change detection and 4 catch trials, and during the data collection phase, they completed 120 experimental and 24 catch trials. There were equal numbers of trials in the *same*, *expand*, and *random* conditions. Color changes were equally distributed across the three conditions and occurred equally frequently at each quadrant.

Results

To determine whether we were able to replicate Jiang et al.'s (2000) results when we procedurally replicated them, we specifically tested whether visual change detection accuracy was similar in the *same* and *expand* conditions and lower than in the *random* condition for the 400-msec encoding condition only. However, a repeated measures ANOVA showed that there was no main effect of condition [$F(2,16) = 3.23, p = .066, \eta_p^2 = .29$].

To determine whether encoding time had an impact on the interaction between the presence of a color change and the location manipulation, we submitted the percentage of accuracy data to a $2 \times 2 \times 3$ ANOVA. Encoding duration (150 vs. 400 msec) was the between-subjects variable, and type of trial (change vs. no change) and condition (*same*,

expand, and *random*) were the within-subjects variables. The only main effect that reached significance was driven by significantly more correct no-change responses ($M = 85.3 \pm 0.02$) than change responses ($M = 92.08 \pm 0.01$) [$F(1,16) = 23.99, MS_e = 0.006, p = .000, \eta_p^2 = .60$].

The three-way interaction did not reach significance [$F(2,32) = 1.035, MS_e = 0.109, p = .837, \eta_p^2 = .061$], suggesting that encoding duration did not differentially impact the critical type of trial and condition interaction [$F(2,32) = 5.54, MS_e = 1.94, p = .009, \eta_p^2 = .26$]. Therefore, in Figure 4, we presented proportion accuracy across the *same*, *expand*, and *random* conditions for change and no-change trials collapsed over the two encoding durations. As in the previous experiments, pairwise comparisons revealed that this two-way interaction was driven by a slight advantage in the no-color-change condition in the configurally congruent trials [$t(17) = 3.11, p = .006$, and $t(17) = 5.00, p = .000$, for *same* and *expand*, respectively], as compared with the equivalent performance in the *random* condition ($t < 1$).

The analyses also revealed that there was a significant encoding duration $\times$ types of trial interaction [$F(1,16) = 6.15, MS_e = 0.006, p = .025, \eta_p^2 = .28$], because of the higher proportion of correct responses in the no-change condition than in the change condition when the encoding duration was 400 msec [$t(8) = 5.88, p = .000$]. No such difference was observed when the encoding time was 150 msec [$t(8) = 1.55, p > .05$].

The other two-way interaction that reached significance was the encoding duration $\times$ condition interaction [$F(2,32) = 4.46, MS_e = 0.003, p = .02, \eta_p^2 = .22$]. This interaction was due to a slight increase in the accurate responses in the *random* condition, as compared with the configurally congruent conditions (*same*, *expand*) only in

Figure 4. Proportions of accuracy across the *same*, *expand*, and *random* conditions for color-change and no-color-change trials in Experiment 3. Error bars represent the standard errors of the means.

the 400-msec condition [$t(8) = 2.55, p = .034$, vs. $t(8) = 1.34, p = .20$]. In this respect, the data actually differed even more from the typical Jiang et al. (2000) pattern, even when encoding time was kept the same.

The signal detection analyses yielded similar results (see Table 3). There was no main effect of condition on d' . The bias measures for the three conditions suggested that people had a greater tendency to report no color changes in the *expand* condition. The fact that people were equally likely to respond *color change* and *no color change* in the *random* condition suggests that, as compared with the *expand* condition, they were more often reporting a color change. These results replicated the pattern observed in the first two experiments.

In addition to the lack of a configuration effect on accuracy, a same-location advantage was evident only in the RT data. A comparison of RTs across the *same*, *expand*, and *random* conditions revealed a significant main effect [$F(2,32) = 8.29, MS_e = 4,428.96, p = .001, \eta_p^2 = .34$]. Post hoc comparisons revealed that this main effect was driven by disproportionately shorter RTs in the *same* (883.78 ± 45.01) condition than in the *expand* (958.67 ± 59.79) and *random* (968.88 ± 62.97) conditions [$t(16) = -3.40, p = .004$, and $t(16) = -3.08, p = .007$, respectively].

Discussion

In Experiment 3, we failed in our attempt to replicate Jiang et al.'s (2000) results, despite a procedural replication. Furthermore, we demonstrated that encoding duration has no effect on visual change detection accuracy. Furthermore, the three-way interaction involving encoding time, along with condition and type of trial, did not reach significance. As in the previous experiments, we demonstrated a change in bias patterns across configurationally congruent and incongruent conditions. Disruption of configurations between the memory and test displays influenced the likelihood of reporting color changes; people were more likely to report a color change when the locations of the objects were randomly changed than when they either remained in the same locations or were placed in expanded-out locations. Thus, when configurations were changed across the two displays, there was more of a bias to respond *color change*. Jiang et al. actually reported a similar finding: There was a stronger *no bias* in the *same* ($c = 3.19$) and *expand* ($c = 2.04$) conditions

than in the *random* condition ($c = 1.22$) in their study. Olson et al. (2004) also reported that in a visual change detection task, when partial spatial configuration was kept identical across two displays, both young and old adults mistakenly reported color changes even in the absence of such changes. However, neither article discussed the implications of these findings.

One noteworthy difference between our results and Jiang et al.'s (2000) results was that their participants were, overall, more sensitive, as measured by d' , than our participants. For the *same*, *expand*, and *random* conditions, they reported d' 's to be 3.78, 3.42, and 1.85, respectively, whereas we, for the respective conditions, found d' 's of 1.99, 2.82, and 2.71. Given similar levels of accuracy in both studies (approximately 85%–90%), the differences in d' suggest that our participants made false alarms more frequently. The differences between false alarm rates across the two samples may actually be indicative of differences in ability and/or strategies employed during the visual change detection tasks. Even though the participants in both studies were naive about the specific predictions tested, it is still possible that they differed in whether or not they previously had been participants in visual change detection experiments. Previously participating in such tasks may implicitly influence how people adopt a criterion to report a change, and if this criterion is set to be more conservative, it could potentially lead to a low false alarm rate. Another possibility is that there may have been baseline ability differences between the two groups of participants; lower ability participants may, in general, set a lower, less conservative criterion, resulting in a higher false alarm rate.

There were two other interesting findings in Experiment 3. As in Experiment 1, only in the RT data did we observe a same-location advantage. We believe that this overall RT effect can be explained with factors similar to those thoroughly discussed earlier. Although there was no main effect of encoding duration on accuracy overall, a longer encoding time did lead the participants to be more accurate in certain conditions. Specifically, there was a two-way encoding duration $\times$ condition interaction, as well as a two-way encoding duration $\times$ type of trial interactions. Overall, individuals were somewhat more accurate on random conditions and no-change conditions when the encoding time was 400 msec, as compared with 150 msec. However, because the three-way interactions were not significant, there is no evidence of differences in bias as a function of encoding time.

Table 3
Mean Sensitivity and Bias Estimates for Experiment 3

Condition	Encoding Duration (msec)			
	150		400	
	d'	c	d'	c
Same	2.26	0.16	1.72	0.13
Expand	2.96	0.35*	2.69	0.39*
Random	2.53	0.01	2.88	0.19

Note—There was no main effect of condition (on d') for either encoding duration. In both conditions, comparison of bias scores against the no-bias criterion revealed a significant *no bias* in the *expand* condition. * $p < .05$.

EXPERIMENT 4

Experiments 1–3 clearly demonstrated that changes in task-irrelevant spatial configurations reduce the conservative bias to report no color changes. Specifically, when spatial configurations changed randomly as compared with when they were kept the same, the participants were more likely to report a color change even when there was none. Thus, we concluded that people were encoding task-irrelevant spatial configuration information. However, contrary to Jiang et al. (2000), this configuration infor-

mation available to the participants did not differentially influence color change detection accuracy or sensitivity across configurally congruent and incongruent conditions. The goal of the present study was to understand when configuration information directly influenced color change detection accuracy.

Even though Experiment 3 procedurally replicated Experiment 3A in Jiang et al. (2000), our findings did not reveal a configuration effect on either sensitivity or accuracy scores. The similar levels of accuracy but much lower levels of d' in our experiment suggested that our sample tended to make more false alarms than did the Jiang et al. sample. This difference could possibly be indicative of strategy differences and/or ability differences across the two samples. Thus, we decided to investigate this issue further by running the visual change detection task in a larger sample and comparing individuals who tended to make more false alarms with those who made fewer false alarms. Given the narrower distributions with smaller samples, previous experiments did not allow us to meaningfully group participants on the basis of performance variables. We predicted that individuals who made fewer false alarms would be more likely to show the configuration effect on sensitivity measures than would individuals who made more false alarms.

Method

Participants. Sixty-one undergraduates with normal or corrected-to-normal vision participated in the experiment. None reported being color-blind. All the participants provided informed consent and were debriefed. Data from 1 participant were eliminated because his overall performance was more than three standard deviations below the group mean, leaving us with 60 participants.

Materials. All the details were the same as those in Experiment 3, except that, here, encoding time was set to 150 msec.

Results

To compare our results directly with those in Jiang et al. (2000), we calculated both percentage of accuracy and sensitivity across conditions. To determine whether percentage of accuracy in the *same* and *expand* conditions was higher than that in the *random* condition, we entered the data into a repeated measures ANOVA, with condition as the within-subjects variable. There was no main effect of condition [$F(2,118) = 0.594, p > .05$]. However, interestingly, when d' was the dependent variable, the repeated measures ANOVA yielded a small yet significant main effect of condition [$F(2,118) = 4.21, MS_e = 0.258, p = .017, \eta_p^2 = .067$]. Post hoc comparisons confirmed that performance in the *same* ($M = 2.62 \pm 0.11$) and *expand* ($M = 2.71 \pm 0.11$) conditions were equal [$t(59) = 1.04, p = .30$]. More critically, performance in the *random* condition ($M = 2.44 \pm 0.08$) was significantly lower than that in the *same* and *expand* conditions [$t(59) = 1.76, p = .08$, and $t(59) = 2.87, p = .006$, respectively].

This pattern of results was not explained by any speed–accuracy trade-offs; there was a main effect of condition on RT driven by the significantly shorter RTs in the *same* condition (975.79 ± 32.99), as compared with the *expand* ($1,024.66 \pm 37.67$) and *random* ($1,022.01 \pm 35.94$) conditions [$F(2,116) = 10.04, MS_e = 4,466.82, p < .001$,

$\eta_p^2 = .148$]. Thus, for the first time, we were able to replicate the Jiang et al. (2000) findings, but only on sensitivity scores.

To test whether individuals who made fewer false alarms were more likely to show the configuration effect, we grouped the participants on the basis of whether their average false alarm rate (responding *change* when there was none) was higher or lower than the median false alarm rate of the full sample. A comparison of high- and low-false-alarm individuals across the three conditions revealed significant main effects of group [$F(1,59) = 93.88, MS_e = 0.49, p < .001, \eta_p^2 = .614$] and condition [$F(2,118) = 6.25, MS_e = 0.49, p < .003, \eta_p^2 = .096$]. These main effects were qualified by a significant condition $\times$ group interaction [$F(2,118) = 3.83, MS_e = 0.271, p < .024, \eta_p^2 = .061$]. As can be seen in Figure 5, performance of those who constituted the high-false-alarm group did not differ across the three conditions [$F(2,64) = 1.63, MS_e = 0.295, p = .204$]. However, those individuals who tended to make fewer false alarms showed a configuration effect [$F(2,52) = 8.99, MS_e = 0.239, p < .001, \eta_p^2 = .257$]. Pairwise comparisons revealed that there was no difference between the *same* and *expand* conditions ($ps > .82$), but performance in the *random* condition was significantly lower than that in the other two conditions ($ps < .003$).

Bias scores (c), as presented in Table 4, confirmed that there was a greater bias to report a change in the *random* condition than in the other two conditions. Whereas a *no* bias was more pronounced in the configurally congruent conditions, in the *random* condition, people were equally likely to report a color change or not. Thus, in the *random* condition, we can argue for an increase in the *yes* bias. This finding is consistent with the bias findings documented throughout Experiments 1–3.

Figure 5. The d' scores across the *same*, *expand*, and *random* conditions for high- and low-false-alarm (FA) groups. Solid bars represent the low-FA group; error bars represent the standard errors of the means.

Table 4
Bias Estimates (c) for Experiment 4

Condition	Overall	High False Alarm	Low False Alarm
Same	0.18	0.07	0.26*
Expand	0.33*	0.39*	0.26*
Random	0.11	0.09	0.12

Note—Bias scores are presented for the whole sample and for the high- and low-false-alarm groups. Comparison of bias measures against the no-bias criterion revealed that in the *expand* condition, there was a greater bias to report no changes. Interestingly, in the *same* condition, for the high-false-alarm group, there was no particular bias observed. * $p < .05$.

Discussion

Consistent with our predictions, in Experiment 4, we demonstrated the configuration effect only among participants who made fewer false alarms and were more sensitive. Even though there was a significant configuration effect in the full sample, closer inspection of the data revealed that the effect size of the condition effect was very small ($\eta_p^2 = .096$). Furthermore, the interaction revealed that only in the low-false-alarm group was there a configuration effect. The d' scores of the low-false-alarm group approached that of the Jiang et al. (2000) sample; whereas their average d' across three conditions was 3.01, for the low-false-alarm group it was 2.81. Also, the performance reached by our low-false-alarm group was higher than the performance we observed throughout Experiments 1–3, in which average d' ranged between 2.40 and 2.50. Furthermore, this select group of participants' false alarm rate was lower than that for the remaining sample across all four experiments (6% vs. 10%). This suggests that the configuration effect reported by Jiang et al. may have been due to strategies employed by a highly select group of participants. The findings reported here also provide an explanation for why we did not observe any confirming evidence for configuration-based representations in change detection scores in the previous experiments. In addition to these findings, as in previous experiments, we found a same location advantage in the RT data and the reduction of the no-color-change bias in the *random* condition.

One interesting and important question that emerges from the last experiment, then, is why configuration information more consistently influences response bias measures than accuracy or sensitivity measures. Our data clearly show that as people encode a set of visual objects, they encode the spatial configuration information. The fact that this information is encoded during the study display does not necessitate the strategic utilization of it during the following stages in the visual change detection task. Those who can utilize such configuration information seem to perform better and report color changes more accurately, especially when the configuration information remains constant. Given the possible difference between groups in the utilization of spatial configuration information, then, one should specifically ask *how* spatial configuration information can be utilized while the visual change detection task is performed.

One possibility is that configuration information can be useful in solving the correspondence problem (Fencsik, 2003). Presence of configural cues may help individuals while they are searching a test display to identify which objects need to be compared with each one of the studied items. If some individuals utilize these cues to establish correspondences in configurally congruent conditions, this may reduce the difficulty of the search phase and prevent representations from further interference in the *same* and *expand* conditions, as compared with the *random* condition. Thus, accuracy may be higher in conditions in which configurations are preserved across displays versus when they are not. Our data suggest that such utilization may be linked to higher sensitivity overall.

Even though configuration information would be useful in establishing correspondences between study and test displays, such cues are not necessary for solving the correspondence problem. For instance, in the particular experiments described in this article, an individual could rely on quadrant information to determine correspondences between objects in study and test displays. Thus, the presence of such cues may not directly influence performance measures. However, our data suggest that it could possibly influence responses at a later stage. Specifically, the reduction of the no-color-change bias observed when spatial configuration information was changed, as in the *random* condition, indicate that changes in task-irrelevant spatial configuration information were leading people to mistakenly attribute a detected yet unidentified change to the color domain. When representations do not allow for the identification of the source of these changes, such task-irrelevant configural changes could influence biases and result in an increase in *color change* responses in *random* conditions. This pattern is more typical of the general college sample employed across these four experiments. It is possible that the reported bias finding is more obvious among lower sensitivity participants because these individuals have a greater inability to ignore task-irrelevant information. There is indeed some evidence that low-capacity individuals store more task-irrelevant information than do high-capacity individuals (Vogel, McCollough, & Machizawa, 2005). This issue merits further research.

The findings in Experiment 4 have implications for previously proposed models of change detection. Fencsik (2003) argued that one of the main problems in visual change detection tasks is how correspondences are established between memory and test displays, before object properties can be directly compared. Establishing correspondences is easy when objects appear in identical or somewhat predictable locations. In the Jiang et al. (2000) paradigm, it was argued that when spatial configurations formed by target objects are expanded, it is easier to establish correspondences, as compared with when objects are randomly moved (Fencsik, 2003). This reduces the search phase necessary to establish correspondences; thus, object representations decay less, and color change detection performance is somewhat preserved. Our experiments reveal that there may be other factors besides preserving configuration information between memory and test dis-

plays that help in building correspondences. For instance, the fact that objects did not change quadrants may have been a sufficient cue helping the viewers establish correspondences. This may explain the equivalent levels of performance observed in the *expand* and *random* conditions in Experiments 2 and 3 and in the low-ability group's performance in Experiment 4.

GENERAL DISCUSSION

The experiments presented in this article have clearly shown two critical aspects of visual change detection performance. First, when people encode visual displays, the spatial configuration of visual objects is encoded. However, not all viewers may utilize this information in the same fashion. This forms the basis of the second take-away point. There may be individual differences in how visual and spatial information are bound together. We will discuss these major findings in turn.

The evidence for the notion that spatial configurations are encoded along with visual object information has come from demonstrations of how this task-irrelevant feature systematically influences color change judgments. Hyun et al.'s (2009) model clearly describes how task-irrelevant dimensions can influence change detection accuracy when task-relevant information is not sufficient for the detailed identification of a change. Across all four experiments, the increase of the *color change* responses when spatial configurations changed in the *random* condition directly suggests that spatial configuration information was available to the participants at the time of their response. Given the task-irrelevant nature of spatial configuration, we believe that the encoding of such information may be "effortless," if not automatic. This conclusion is in line with previous conclusions of Simons (1996) and Olson et al. (2004).

Even though the extraction of spatial configuration information may be effortless, this does not automatically guarantee that information is bound to featural (object) information. We argue that effective binding of spatial configuration and object information may be open to strategic influences and/or determined by general ability. It is quite possible that our low-false-alarm group in Experiment 4 showed a configuration effect because of how they more effectively (and maybe even strategically) bound visual and spatial information while encoding the study display, whereas others did not. This might have allowed them to utilize configuration information better to establish correspondences. On the other hand, most other viewers may have encoded spatial configuration alongside object information; but if not tightly bound to object information, such configural cues may not have been sufficient to influence early visual change detection stages. This idea is contrary to the model proposed by Jiang et al. (2000), who argued that the visual features of the objects are stored in a configural manner. Most of our data do not directly support the claim that the colors of the items in the memory set were stored in a configural representation. One possibility is that most viewers stored a nonconfigural representation of the colors in their object working memory

system and a separate representation of the configuration in their spatial working memory system. The changes in configuration led to a change in response bias because participants were unable to determine with 100% accuracy whether a perceived change was due to the colors or to the configuration. Future research has to determine whether spatial configuration information would influence color change judgments differently if people were asked to remember more than four items, pushing them over their capacity limitations. It is possible that as people attempt to maintain more than four visual objects in memory, spatial configuration information becomes less available, and the bias effects reported here diminishes. Alternatively, if configuration information is easier to encode and preserve than visual object information, then, as the visual short-term tasks become more difficult, effects of bias on judgments may increase. These options remain open to empirical testing.

The existence of strategic differences in how visual and spatial information are integrated highlights the need for more comprehensive efforts in investigating how individual-difference variables influence basic visual information processing tasks. Specifically, future research should identify independent measures of individual abilities that are predictive of effective coding of spatial layout and item information.

AUTHOR NOTE

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NOTE

1. When the same paradigm was tested with three instead of four conditions (*same*, *shrink*, and *random*), we still did not find accuracy in the *same* and *shrink* conditions to be equal and higher than that in the *random* condition (Boduroglu et al., 2009). In neither of the culture groups did we observe a configuration effect; the participants from two groups differed only in their performance in the *shrink* condition, with East Asians performing significantly worse.

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