Implicit, Long-Term Spatial Contextual Memory

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Learning and memory of novel spatial configurations aids behaviors such as visual search through an implicit process called *contextual cuing* (M. M. Chun & Y. Jiang, 1998). The present study provides rigorous tests of the implicit nature of contextual cuing. Experiment 1 used a recognition test that closely matched the learning task, confirming that memory traces of predictive spatial context were not accessible to conscious retrieval. Experiment 2 gave explicit instructions to encode visual context during learning, but learning was not improved and conscious memory remained undetectable. Experiment 3 illustrates that memory traces for spatial context may persist for at least 1 week, suggesting a long-term component of contextual cuing. These experiments indicate that the learning and memory of spatial context in the contextual cuing task are indeed implicit. The results have implications for understanding the neural substrate of spatial contextual learning, which may depend on an intact medial temporal lobe system that includes the hippocampus (M. M. Chun & E. A. Phelps, 1999).

Memory research rests heavily on the distinction between explicit and implicit memory (Schacter, 1987; Squire, Knowlton, & Musen, 1993). Explicit (declarative) memory supports the ability to consciously retrieve and declare past facts and events. Implicit (nondeclarative) memory supports improved performance in a variety of perceptual and motor tasks, although observers cannot recall or articulate the learned information.

This taxonomy was based on a rich body of empirical and theoretical work. The two types of memory have different characteristics and are mediated by dissociable memory systems in the brain (Gabrieli, 1998; Squire et al., 1993; Tulving & Schacter, 1990). Explicit memory is consciously accessible in a fast, flexible manner, and it depends on an intact medial temporal lobe system, including the hippocampus (Squire, 1992; Squire & Zola-Morgan, 1991). Implicit memory influences behavior in a less flexible but more durable manner without reaching awareness. Most forms of implicit memory do not rely on the medial temporal lobe system. Thus, patients with damage to medial temporal lobe structures reveal severe amnesia for declarative information but show normal performance in implicit memory tasks (Cohen & Squire, 1980; Corkin, 1968). This dissociation cannot be explained by proposing that implicit memory is merely a more robust form of explicit memory, because the converse dissociation also exists. Patients with damage to nonhippocampal brain structures (e.g., occipital cortex) may reveal impaired implicit memory (as indicated by perceptual priming) but spared explicit memory (Gabrieli, Fleischman, Keane, Reminger, & Morrell, 1995).

We recently developed a new paradigm called *contextual cuing* to study implicit learning and memory using a perceptual task (Schacter, 1994). Contextual cuing refers to improved performance in visual search tasks based on learned associations between targets and surrounding visual context (Chun & Jiang, 1998, 1999; Chun & Nakayama, 2000; Olson & Chun, 2001). One version of the contextual cuing task requires spatial learning. Participants performed visual search for a target (e.g., a rotated T) presented among distractors (e.g., rotated Ls). Every trial contained a target, which was a T rotated 90° either to the right or to the left. Participants were instructed to detect the target as quickly as possible, pressing one of two keys corresponding to the orientation of the target. The primary measure was the response time to report the target. Accuracy was always high.

In such search tasks, the target and surrounding distractors form a spatial layout on the computer screen. Visual context can be defined as the global configuration of all the items. Prior to the learning phase, several random configurations were generated. These configurations were repeated across blocks of trials during the learning phase. The target in each of these displays appeared in a consistent location relative to its context from repetition to repetition. Thus, the global spatial layout provided a predictive cue to the location of the embedded target. If observers were sensitive to the spatial context of the targets, and if they could encode and discriminate the different spatial configurations as well as their corresponding target locations, then search should improve with repetition. In the assessment of this learning, search performance for targets appearing in these repeated Old displays was contrasted with that for targets appearing in New displays, randomly generated for each block.

The main finding was that search was faster for targets appearing in Old displays after about 5–10 repetitions. This is the contextual cuing effect, reflecting the fact that visual context cued attention to the target, facilitating search. The contextual cuing task requires relational, configural learning processes because each

display was defined by a unique configuration of multiple item locations, and participants had to associate different configurations with different embedded target locations (Cohen & Eichenbaum, 1993; Eichenbaum, 1992; Rudy & Sutherland, 1994). The memory traces for spatial context were specific enough to discriminate one context from another (Logan, 1988).

Another key finding was that the memory traces for spatial context were implicit. When presented with an Old–New recognition test immediately following visual search, participants performed at chance in determining whether a layout was Old or New. The implicit nature of contextual cuing provides the motivation for the present work. Research on explicit versus implicit memory necessarily revolves around how to define whether a task is implicit or not (Frensch, 1998; Stadler & Roediger, 1998). Thus, we aim to provide converging evidence to further bolster the claim that spatial contextual cuing represents an implicit learning task that produces memory representations that are also implicit.

One limitation of the recognition test used by Chun and Jiang (1998) is that participants had to discriminate Old and New displays based on a sense of familiarity or perceptual fluency (Jacoby, 1991; Johnston, Dark, & Jacoby, 1985). However, such familiarity judgments may not be the most sensitive measure for explicit memory as they reflect memory traces that may be different from those actually used to benefit target localization in search. This discrepancy casts doubt on whether explicit memory of context information is truly absent. For instance, observers may have conscious access to the target location within particular configurations, without being aware of having seen the global configuration. It is, therefore, important to use an explicit memory test procedure that engages processes that are as similar as possible to the processes engaged during the search task (learning phase). In Experiment 1, we used an explicit memory test that asks participants to estimate the location of the target. This test requires participants to explicitly report the information, target location, that benefits the implicit task (visual search). If participants fail in this task, it would reinforce the conclusion that the contextual cuing task relies on implicit representations.

More broadly, implicit representations are known to have a number of other properties, such as insensitivity to instructions of explicit memorizing (Curran & Keele, 1993; Frensch & Miner, 1994; Jiménez, Méndez, & Cleeremans, 1996) and the retention of learned information over a long period (Cave, 1997; Cave & Squire, 1992; Gooding, Mayes, & Meudell, 1994; Jacoby & Dallas, 1981; Mitchell & Brown, 1988; Tulving, Schacter, & Stark, 1982). The goal of this study is to show that memory representations in the contextual cuing paradigm exhibit these other characteristics of implicit memory. In Experiment 2, we tested how contextual learning and memory is affected by instructions to explicitly encode the repeated context. In Experiment 3, we tested the robustness of implicit contextual cuing after a retention delay of 1 week.

Experiment 1

To provide a stronger test of potential contributions of explicit memory to contextual cuing, in Experiment 1 we used a new explicit memory task different from the Old–New familiarity judgment task used previously (Chun & Jiang, 1998; Chun & Phelps, 1999). The present explicit memory task required target localization, thus making it more similar to the search task. Specifically,

during the testing phase, we substituted the target with a distractor at the location of the target, and instead of asking participants to conduct a speeded search, we asked participants to guess at their leisure the approximate location of the substituted target. In other words, given a certain global configuration, where was the target likely to occur?

Increasing the similarity between the learning task and the test procedure improves the sensitivity and validity of the explicit memory test. According to the information criterion of Shanks and St. John (1994), an awareness test should tap the same type of knowledge that supported performance in the corresponding implicit test. For example, in serial reaction time (SRT) tasks, participants improve at responding to a fixed sequence of visual target locations. In assessing whether sequence knowledge was implicit or explicit, it is not sufficient to simply ask participants to make familiarity judgments to a sequence. A better, more sensitive, test is to ask participants to explicitly predict the location of the target for the subsequent trial (Willingham, Nissen, & Bullemer, 1989). The sequential prediction and generation task is better because it is more closely matched to the type of sequential responses made during the serial reaction time task itself (the original implicit learning measure). It thus satisfies the information criterion and provides an objective measure of whether sequence knowledge was explicit in SRT tasks. Interestingly, this measure revealed that some participants benefited from reportable knowledge of learned sequences. However, several other participants performed at chance levels in this "generate" task, despite significant learning in the SRT task. This shows that SRT learning can be implicit. Analogous to this, our "guessing" task provides a sensitive, objective measure for the associations between spatial context and target location.

In the present study, participants performed 24 blocks of visual search and then performed an explicit guessing task. Our guessing task presented Old or New displays in which the target was substituted by a distractor. For each display, participants were required to guess which quadrant of the display was most likely to contain the target. Thus, the explicit recognition task required the same type of knowledge that would have benefited the search task. If contextual cuing in the search task relied on explicit knowledge of where to look in Old displays, then participants should correctly guess the target locations for Old displays at above-chance levels.

Method

Participants. Eighteen individuals participated as paid volunteers or in partial fulfillment of an introductory psychology course requirement. Experiments 2 and 3 of this study recruited new participants from the same participant pool as in Experiment 1. All participants reported normal or corrected-to-normal visual acuity. None of them were aware of the purpose of this study. In this experiment, data from 2 participants were removed from the analyses because of computer hardware problems during data collection.

Procedure. For the search task, the two main variables were condition (Old vs. New) and block (1–24). The Old set of stimuli consisted of 12 randomly generated unique configurations that were repeated across blocks, each appearing once per block. A target, a randomly chosen left or right rotated T, always appeared in the same location within a given configuration, so the configuration was predictive of the target location (but not target identity or motor response). The New set consisted of 12 different configurations that were newly generated for each block to serve as a control baseline.

To control for the repetition of target location, the locations of the target in the New set were also repeated from block to block. That is, the target appeared equally often in 24 possible locations throughout the experiment: Twelve target locations were used in the Old configurations, and the other 12 were used in the New configurations. Hence, any difference in performance must be attributed to learning of the association between the invariant spatial contexts and the target location rather than absolute target location probability effects. In addition, each condition contained an equal number (3) of target locations in each of the four quadrants. The distractor locations in each configuration were randomly sampled from all possible locations including target locations used in other configurations. Configurations were generated separately for different participants.

The search task consisted of 24 blocks of 24 trials each (12 Old and 12 New) for a total of 576 trials. Each display contained 12 items (each subtended 1.1 cm × 1.1 cm): one target and 11 distractors. The items were randomly positioned in an invisible 8 × 8 matrix that subtended 17.5 cm × 17.5 cm. Each quadrant contained three items. The target was a T stimulus rotated 90° to the right or to the left. Participants pressed one of the two keyboard keys corresponding to whether the bottom of the T was pointing to the right or to the left. The distractor stimuli were L shapes presented randomly in one of four orientations (0°, 90°, 180°, or 270°). The identities of the distractors within their respective spatial locations in Old configurations were preserved across repetitions. A target was presented on every trial. This target was randomly chosen on each trial, so that the identity of the target (right or left T) and its corresponding response (right or left key press) did not correlate with target location or the spatial configurations. The stimuli were heterogeneously colored with an equal number of red, green, blue, and yellow items. These colors were randomly assigned to each of the items within a configuration. An equal number of targets was presented in each color for each configuration condition (Old–New). The color assignments of all items in Old configurations were preserved across repetitions. The color of targets appearing within any given spatial location was preserved across blocks for New configurations.

The participant pressed the space bar to begin each block. Each trial started with a small white dot (0.3 cm × 0.3 cm) appearing in the middle of a computer screen for fixation. After a brief pause of 500 ms, the array of stimuli appeared on the screen. Participants searched for the target and pressed a corresponding key as soon as possible upon detection. They pressed the Z key if the target was pointing left, and the ?/ key if it was pointing right. The response cleared the display with a blank screen, and feedback was given in the form of a brief high-pitched chirp for correct responses or a prolonged low-pitched tone for errors. After a 1-s pause, the following trial was initiated by the computer. A mandatory break of 10 s was given at the end of each block of 24 trials, after which participants were free to proceed to the next block, or rest further if needed.

The experiment began with instructions followed by a practice block of 24 trials to familiarize participants with the task and procedure. The spatial configurations used in practice were not used in the actual experiment. Participants were not informed that the spatial configurations of the stimuli in some trials would be repeated, nor were they told to attend to or encode the global array. They were not warned about the recognition test at the end of the experiment. They were simply given instructions on the visual search task procedure and shown sample displays of how the targets and nontargets looked. It was stressed that they should respond as quickly and as accurately as possible.

At the end of the final block of the visual search task, the experimenter came into the room and described the following sequence of events to be presented on the computer. The computer first queried whether participants had noticed the configuration repetition manipulation and, if so, at which block they noticed the repetitions and whether they had tried to explicitly memorize the spatial layouts of the display. In addition, regardless of whether the participant had noticed the repetition, every participant performed a target location guessing test for the configurations presented throughout the search session.

The guessing task was simply a standard block of visual search displays comprising 12 Old distractor configurations and 12 New distractor configurations. The target was substituted by an identically colored distractor at the target location. Participants were instructed to guess which quadrant of the display was most likely to contain the substituted target given the configuration shown to them. They made their responses using the keyboard. The guessing task was not speeded. The entire experiment took around 40 min to complete.

Apparatus and stimuli. The experiment was conducted on a Macintosh computer using MacProbe software (Hunt, 1994). The stimuli and apparatus were the same as described in Chun and Jiang (1998). Experiments 1 and 2 were conducted on 17-in. (43.18-cm) monitors. Experiment 3 was conducted on 15-in. (38.10-cm) monitors. To provide a reference for segregating the screen into different quadrants, tick marks (1.25-cm-long light gray short lines running from the screen edge toward fixation) were provided at the center of each side of the display. These were present for every trial throughout the entire experiment.

Results

Search task. The mean RT for all correct trial responses within a block was computed separately for each condition, and these were submitted to repeated-measures analysis of variance (ANOVA) with condition (Old vs. New) and block (1–24) as factors. In this and all following experiments, we filtered out incorrect trials and trials with RT outside 3 standard deviations of each individual participant's mean. The second criterion removed only 1.6% of the data. Accuracy was high: $M = 99\%$, $SE = 0.26\%$, for the New condition; $M = 99\%$, $SE = 0.28\%$, for the Old condition. The two conditional means did not differ from each other, $t(15) = 0$, *ns*.

Significant contextual cuing was observed, as evidenced by faster search for targets in Old displays compared with New displays (Figure 1). There was a main effect of condition, $F(1,$
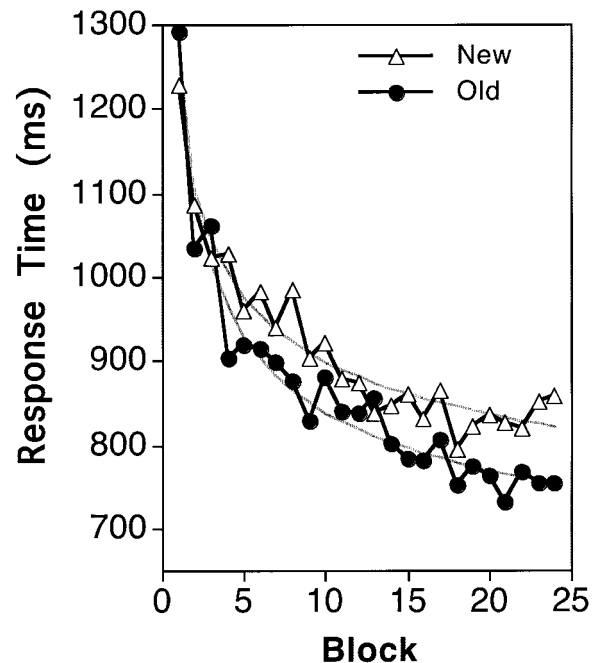

Figure 1. Search performance in Experiment 1. The contextual cuing effect is reflected by the difference in Old and New condition search performance. The grey lines represent the best-fitting power functions through the group mean data for the Old and New conditions separately.

15) = 8.42, $p < .011$, and a main effect of block, $F(23, 345) = 220.53$, $p < .0001$, showing general learning. Important to note, there was a significant interaction between block and condition, $F(23, 345) = 1.70, p < .024$. Pairwise comparison restricted on the first block and the last block showed that the Old condition did not differ from the New condition in Block 1, $t(15) = -1.186, p > .25$, but was significantly faster in Block 24, $t(15) = 3.137, p < .007$.

To further quantify the trend for faster learning in the Old condition, we estimated the parameters of power functions that were fit to the individual RT data for each condition (J. R. Anderson, 1982; Newell & Rosenbloom, 1981; Logan, 1988). We chose to use power functions instead of exponential functions to fit the data (Heathcote, Brown, & Mewhort, 2000) because contextual cuing is well explained by instance theory (Chun & Jiang, 1998), which predicts power functions (Logan, 1988, 1992) and also because exponential functions did not yield better fits for our data set.

The power function takes the form, $RT = a + bN^{-c}$, where RT is the search response time, N is block number, constant a represents the asymptote of learning, constant b is the difference between initial and asymptotic performance, and exponent c is the learning rate. We were interested in two values: the initial level of performance, which is represented by a + b, and the learning rate, measured by exponent c. Contextual cuing predicts that a + b should be equivalent for the New condition and the Old condition because the displays do not differ in any way prior to learning. As learning progresses when displays are repeated across block N, performance should decrease faster for the Old condition than the New condition, and this will be reflected in the exponent c. A larger c represents a steeper learning rate. Hence, c should be larger for the Old condition than the New condition.

In fitting the data, we constrained asymptotic performance, a, to be greater than 0 under the assumption that human reaction times cannot be 0. In addition, we assumed that in the limit, the ultimate level of asymptotic performance should be equal for the New condition and the Old condition. Hence, the fits were constrained so that both conditions share a common value for constant a that represents asymptotic performance. The reasoning is that although the number of possible contexts and target locations in our search task is extremely large, it is nevertheless finite. Thus, if participants were to experience an infinite number of trials in this task, performance in the New condition should eventually converge in the limit to that of the Old condition. Finally, because of huge individual variability, we found it necessary to constrain the learning parameter to be 1 or less. Although this may seem arbitrary, other surveys have typically reported estimates for learning parameter, c, to be typically below 1 for a wide variety of tasks (Logan, 1992; Newell & Rosenbloom, 1981). Especially for all the search experiments in this article, fitting power functions to the group mean data yielded exponent parameters that were always below 0.44. Of the 54 participants tested in the three experiments of this article, only 2 participants in Experiment 1 had their exponent c parameters constrained to 1. Important to note, the 2 participants who required this constraint both exhibited steeper learning curves in the Old condition than in the New condition. Thus, constraining the parameter c to be less than 1 did not distort the parameter estimates or their patterns; this procedure just helped reduce extreme values and variability for Experiment 1.

After estimating parameters for each individual participant, we obtained the arithmetic mean of the parameters as follows. The mean estimate for the learning parameter, c, was 0.321 for the New condition and 0.439 for the Old condition. The difference was significantly different, $t(15) = 2.40, p < .05$, demonstrating a significant contextual cuing effect. The mean estimate for asymptote, a, was 421 ms. The mean estimate for the overall magnitude of learning, b, was 827 ms for the New condition and 873 for the Old condition. Thus, the mean estimate for the initial level of performance, a + b, was 1,248 for the New condition and 1,294 for the Old condition. The difference was not significant, indicating that performance did not differ at the beginning of learning. The goodness of fit of these parameter estimates to the group mean data was $r^2 = 0.94$ for the New condition and $r^2 = 0.95$ for the Old condition. The fit was reasonably good, but to additionally confirm that the learning curves for the group mean data did not deviate significantly from the averaged individual data (R. B. Anderson & Tweney, 1997; Heathcote et al., 2000; Myung, Kim, & Pitt, 2000), we fitted power functions to the group mean data. Figure 1 shows these fits to the group mean data, and the functions were New $RT = 558 + 668N^{-0.291}$ and Old $RT = 558 + 708N^{-0.402}$. These parameter estimates fell within the 95% confidence intervals around the respective means of the individual data parameters. In summary, the learning rate was steeper for the Old condition, and the initial levels of performance were comparable between the two conditions.

Explicit guessing task. Mean accuracy was computed for the guessing task. This was simply the average number of trials that participants correctly guessed the target location for a given target-substituted display divided by the total number of trials. For each condition, perfect performance is 12/12, and the expected number of correct hits is 3/12 (25%) because there was an equal number of targets in each quadrant. Modeling recognition performance as a binomial distribution, the expected standard deviation is 1.5, and the 95% confidence interval lies between 0 and 6 hits.

The mean for correctly guessing target locations in Old displays was 27%, which was not significantly better than chance (25%), $t(15) = .637, p > .50$. The mean for correctly guessing target locations in New displays was 20%, which did not differ from chance, as one would expect, $t(15) = -1.775, p = .096$. The difference between New and Old conditions was not significant, $t(15) = -1.784, p = .095$. All of the participants fell within the 95% confidence interval in all conditions.

Five of 16 participants reported having noticed that some displays were repeating, none of them reported that they had tried to remember the repeated configurations. For these 5 participants, we averaged the block number at which they reported having noticed that displays were repeating. The mean estimate was Block 9. The number of "aware" participants was too small for us to perform a reliable comparison between the aware and unaware participants. Nevertheless, we entered awareness as one of the factors in the ANOVA test and found that this factor did not affect guessing performance ($p > .20$). The aware participants showed a numerically smaller contextual cuing benefit averaged over the course of the entire experiment ($M = 36$ ms, $SE = 40$), compared with the unaware participants ($M = 60$ ms, $SE = 24$). This difference did not reach statistical significance, $F(1, 14) < 1$, *ns.*

Discussion

Participants exhibited no evidence of explicit memory or knowledge of where targets should be located within Old configurations that were repeatedly presented throughout the experiment. This finding stands in contrast to the significant benefit in search performance for targets in Old displays. The results strengthen the claim that contextual cuing is driven by implicit representations.

The guessing task used here is more sensitive than the Old/New familiarity task in earlier contextual cuing studies because the guessing task directly queries the knowledge, namely, target location, that facilitates search (the implicit measure). This satisfies the information criterion proposed by Shanks and St. John (1994) and used in other implicit learning paradigms (e.g., Willingham et al., 1989). One odd aspect of our results was the numerically better performance for guessing target locations in Old displays compared with those for New displays (27% vs. 20%, respectively). However, this apparent difference should be interpreted as noise because such a pattern was not observed in two replications below and several other replications from our lab (Chua & Chun, in press).

Experiment 2

Another important feature of implicit learning and memory is that they should not be affected by explicit instruction. For example, a number of studies have shown that sequence learning tasks involve both intentional and incidental learning. Explicit instruction and intention to learn the sequences facilitated performance, but this additional benefit of instruction disappeared even as implicit learning persisted when complex, probabilistic sequences were used or when participants had to perform a demanding secondary task (Curran & Keele, 1993; Frensch & Miner, 1994; Jiménez et al., 1996). Similar findings have been shown for artificial grammar learning tasks, although explicit processes can help under certain conditions (Dulany, Carlson, & Dewey, 1984; Reber, Kassin, Lewis, & Cantor, 1980). In general, explicit instruction does not enhance the implicit component of sequential or artificial grammar learning.

All of the existing work on contextual cuing involved incidental learning tasks. Participants were never informed about the repetition manipulation, and they were never instructed to try to encode the contextual displays. Will explicit instruction impact contextual cuing and subsequent explicit memory performance? If explicit learning and memory are a component of contextual cuing, the Old/New condition difference in search performance should be boosted by explicit instructions. Explicit guessing performance should also improve if contextual cuing is partly driven by explicit retrieval of associations between repeated contexts and embedded target locations.

Method

All of the methods and procedures were identical to Experiment 1. The only difference was that during the instruction phase, participants were given additional information about the task. They were informed that half of the displays would repeat across blocks and that targets would appear in consistent locations within repeated configurations. Moreover, they were told that recognizing repeated displays would benefit search performance, so they should "pay attention to the overall display configuration (i.e., the spatial layout of the object array) as this information will help you locate

the target more quickly." Finally, they were warned that they would be asked about the displays at the end of the study. The instructions also emphasized that the primary task was to find the target as quickly as possible. This was necessary to help ensure that search performance would be comparable to that of the incidental learning task in Experiment 1. These instructions were provided after participants had performed a few practice trials that familiarized them with the basic search task and the appearance of the displays.

Following the search task, participants were tested in an explicit memory task using the target-quadrant guessing test of Experiment 1. The only other difference from Experiment 1 occurred in the wording of one of the questions presented immediately before the guessing test. Instead of whether they had noticed any repetitions (see Experiment 1), participants were asked, "Did you *recognize* whether certain configurations (spatial layout) of the stimuli were being repeated from block to block (press *Y* or *N*)?"

Results

Search task. During visual search, accuracy was high in both the New ($M = 97\%$, $SE = 0.67\%$) and the Old ($M = 97$, $SE = 0.66\%$) conditions, with no significant difference between the two, $t(15) < 1$, *ns*.

Search was faster for Old displays compared with New displays (Figure 2), demonstrating contextual cuing. There was a main effect of condition, $F(1, 15) = 7.37$, $p < .016$, and a main effect of block, $F(23, 345) = 31.46$, $p < .0001$. The interaction between condition and block did not reach significance, $F(23, 345) = 1.10$, $p > .344$, perhaps because of the fact that the Old condition was faster than the New condition in all but the first block, as visual inspection of Figure 2 indicates. The trend for faster learning in the Old condition was confirmed by the mean estimated parameters of the power functions that were fit to each participant's RT data for
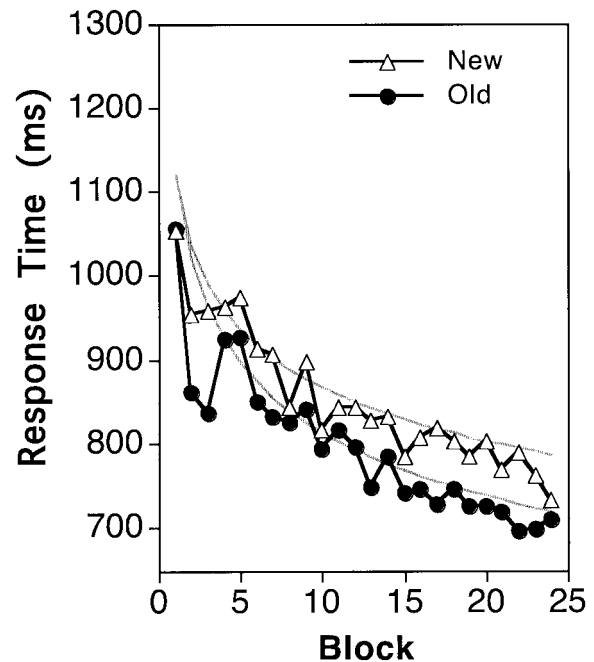

Figure 2. Search performance in Experiment 2. The contextual cuing effect is reflected by the difference in Old and New condition search performance. The grey lines represent the best fitting power functions through the group mean data for the Old and New conditions separately.

each condition, as done in Experiment 1. The mean estimate for the learning parameter, c, was 0.180 for the New condition and 0.228 for the Old condition. The difference was significantly different, $t(15) = 2.63$, $p < .05$, demonstrating a significant learning effect. The mean estimate for asymptote, a, was 187 ms, and the mean estimates for the overall magnitude of learning, b, was 930 ms for the New condition and 950 for the Old condition. Thus, the mean estimate for the initial level of performance, a + b, was 1,118 ms for the New condition and 1,138 for the Old condition. The difference was not significant, indicating that performance did not differ at the beginning of learning. The goodness of fit of these parameter estimates to the group mean data was $r^2 = 0.89$ for the New condition and $r^2 = 0.91$ for the Old condition. In addition, we fitted power functions directly to the group mean data. As shown in Figure 2, the functions were New $RT = 1 + 1115N^{-0.11}$ and Old $RT = 1 + 1121N^{-0.14}$. The c parameter estimate fell within the 95% confidence interval around the individual means, but the a and b estimates were outside their respective 95% confidence intervals. However, we were interested in the initial levels of performance, measured by a + b, for both the New (1,116 ms) and Old conditions (1,122 ms), and these estimates were very close to those estimated from the individual data. In summary, the learning rate was steeper for the Old condition, and the initial levels of performance were comparable between the two conditions.

To examine whether explicit instruction had an impact on the magnitude of contextual cuing, we entered Experiment 1 (no instruction) and Experiment 2 (explicit instruction) as factors in a mixed-factor ANOVA test involving experiment, condition, and epoch (first vs. last). None of the effects (main or interaction) involving the experiment factor was significant in the RT measure (all $ps > .15$, estimated power $> .60$) or the accuracy measure (all $ps > .20$). In fact, numerically, the contextual cuing benefit was smaller with explicit instructions (57 ms) than without such instructions (73 ms). Thus, explicit instruction did not lead to increased learning.

Explicit guessing task. Although participants did not show a larger contextual cuing effect in the search task under conditions of explicit instructions, their explicit memory of the learned information may be enhanced by such instructions. This possibility, however, was not supported by their explicit guessing data. The mean for correctly guessing target locations in Old displays was 23%, which was not significantly better than chance, $t(15) = -.719$, *ns.* The mean for correctly guessing target locations in New displays was 25%, which did not differ from chance either, $t(15) = 0$, *ns.* The difference between New and Old conditions was not significant, $p > .20$. All of the participants fell within the 95% confidence interval around 25% correct in all conditions. To show the effect of explicit instructions more directly, we performed an ANOVA test on the guessing performance using experiment, condition, and block as the three factors. None of the effects involving experiment was significant, all $ps > .20$, indicating that explicit instructions failed to enhance explicit memory.

Only 5 of 16 participants reported having recognized that some displays were repeating, and it is interesting that none reported to have tried to remember the configurations. On average, such repetitions were reported to have been noticed at around Block 7. The factor of reported awareness did not affect guessing performance ($ps > .20$). The mean contextual cuing was 84 ms ($SE = 26$) for unaware participants, and was 1 ms ($SE = 36$) for aware

participants, this difference approached statistical significance, $F(1, 14) = 3.33$, $p < .089$. If anything, explicit attempts to detect and learn repeating contexts was detrimental.

Discussion

Participants did not benefit from knowledge of the repetition manipulation. Although participants were aware that attending to the repeated displays would potentially benefit performance, they were unable to use this information to improve search or target location guessing. In fact, many participants failed to confidently recognize that displays were repeating from block to block.

Although it is possible that participants simply ignored our instructions, we think it is more likely that participants were unable to benefit from the explicit learning instructions. The results are consistent with the experimenters' introspection of this task. Repeated spatial layouts were intermixed among hundreds of other novel configurations, making the displays extremely difficult to discriminate and encode. In such situations, implicit mechanisms may provide a more powerful mode of learning (Berry & Dienes, 1993; Reber, 1989; Stadler & Frensch, 1998). This observation has been made in the SRT literature also. Easy tasks, such as first-order association learning in SRT, typically benefit from explicit instruction and can be learned under distraction. However, more difficult, probabilistic and second-order sequences do not benefit from explicit instruction (Curran & Keele, 1993; Frensch & Miner, 1994; Jiménez et al., 1996). In addition to the complexity of the displays, the demands of the search task itself may have precluded any benefit from explicit knowledge or intention to learn, mirroring similar findings in sequence learning tasks that employed heavy task loads (Curran & Keele, 1993; Jiménez et al., 1996).

In summary, our results probably reflect participants' inability to benefit from explicit instruction due to the difficulty of our configural displays and the primary search task. This finding strengthens the claim that contextual learning and cuing occur in an implicit, incidental manner.

Experiment 3

Implicit representations are robust and durable over time, lasting for days, weeks, even months in both normal observers and patients with amnesia (Cave, 1997; Cave & Squire, 1992; Gooding et al., 1994; Jacoby & Dallas, 1981; Mitchell & Brown, 1988; Tulving et al., 1982). If contextual cuing is supported by implicit memory traces, then memory for spatial context in this paradigm should also persist for a relatively long time beyond the experimental session. To test this, we asked participants to return for a second session 1 week after their first session. Old displays repeated in the second session were taken directly from the first session. If contextual cuing is driven by implicit spatial context representations that have a long time course, we should observe significant contextual cuing in the second session for Old displays that were learned 1 week earlier.

Method

The methods for Session 1 were identical to the aforementioned procedure, except that only the visual search task was performed. Modifications were made to Session 2 to allow us to measure savings from Session 1 while controlling for new learning that may occur during Session 2. Instead of using New displays that were randomly generated for each block, we

generated a novel set of New displays prior to Session 2 and repeated these across blocks in Session 2. These will be referred to as Repeated-New displays. By comparing Repeated-New with Old displays repeated from Session 1, we can factor out any effects of learning that occurred within the second session. If a difference exists between the Repeated-New and Old displays, this must be due to prior exposure to the Old displays in the first session.

In Session 1, participants performed 30 blocks of search; in Session 2, participants performed 8 blocks of search followed by 1 block of explicit guessing test. Twenty-two participants were tested in this experiment.

The stimuli were similar to Experiment 1 except that all items were monochromatic and the L distractors had small offsets that made them more similar to the rotated T targets. These minor changes were made to increase the generality of our findings. In particular, the offsets in the L distractors serve to increase their form similarity with the T target, a manipulation that increases the difficulty of the search task (Duncan & Humphreys, 1989). We wished to make the search task harder to avoid ceiling effects of learning across the two sessions.

The explicit guessing test consisted of three types of target-substituted displays: 12 Old displays, which were repeated throughout Sessions 1 and 2; 12 Repeated-New displays, which were repeated throughout Session 2 only; and 24 New displays, which were completely novel. Participants were asked to guess from each display which quadrant was most likely to contain the target.

Results

Search task. Accuracy was high in performing this task. Mean accuracy in Session 1 was: $M = 98\%$, $SE = 0.66\%$ for the Old condition, and $M = 98\%$, $SE = 0.56\%$ for the New condition. Accuracy was not affected by whether the patterns repeated or not, $t(21) = 0.047$, *ns*. In Session 2, mean accuracy was 99% ($SE = 0.18\%$) for the Old condition and 99% ($SE = 0.16\%$) for the Repeated-New condition. Again, accuracy was not affected by condition, $t(21) = 0.237$, $p > .50$.

For the RT analysis, a contextual cuing effect was observed in Session 1, as evidenced by a main effect of condition, $F(1, 21) = 17.956$, $p < .001$. There was a main effect of block, $F(29, 609) = 18.680$, $p < .001$, but the interaction between condition and block was not significant, $F(29, 580) < 1$. The lack of interaction was presumably due to the gradual learning effect spread across 30 blocks (see Figure 3). However, a power function analysis confirmed faster learning in the Old condition. The mean estimate for the learning parameter, c, was 0.166 for the New condition and 0.226 for the Old condition. The difference was significantly different, $t(21) = 3.41$, $p < .003$, demonstrating a significant learning effect. The mean estimate for asymptote, a, was 590 ms, and the mean estimate for the overall magnitude of learning, b, was 2,253 ms for the New condition and 2,241 for the Old condition. Hence, the mean estimates for initial performance, a + b, were 2,843 for the New condition and 2,831 for the Old condition. The difference was not significant, indicating that performance did not differ at the beginning of learning. The goodness of fit to the group mean data was $r^2 = 0.86$ for the New condition and $r^2 = 0.89$ for the Old condition. In addition, we fitted power
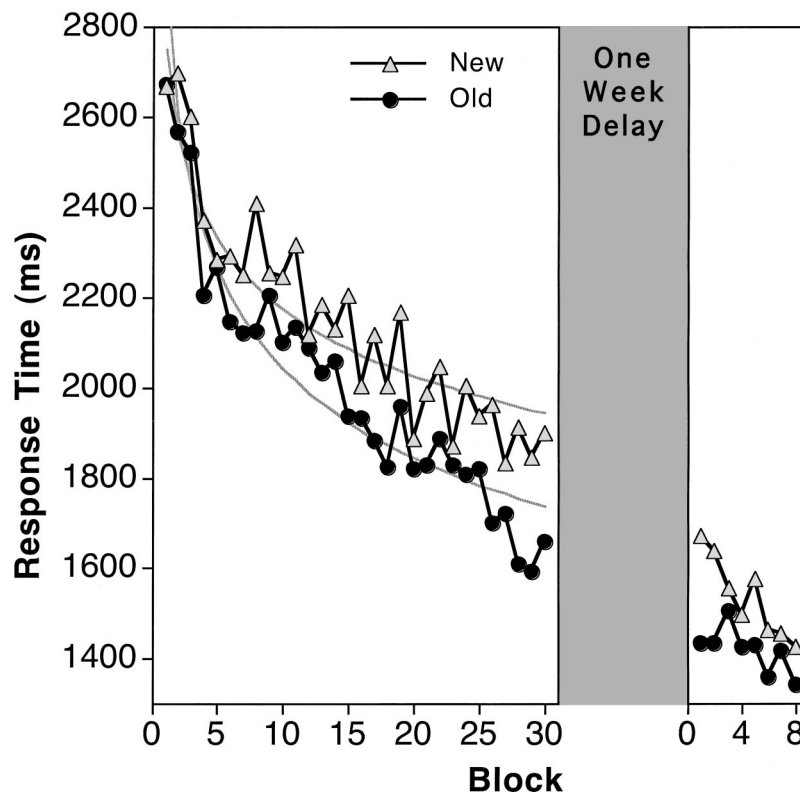

Figure 3. Search performance in Experiment 3. The contextual cuing effect is reflected by the difference in Old and New condition search performance. Participants were tested in two sessions, separated by 1 week. Note that contextual cuing is present even within the first block of Session 2. The grey lines represent the best fitting power functions through the group mean data for the Old and New conditions separately.

functions directly to the group mean data. As shown in Figure 3, the functions were New RT = $172 + 2580N^{-0.110}$ and Old RT = $172 + 2720N^{-0.162}$. All parameter estimates fell within the 95% confidence intervals around the respective individual parameter means. In summary, the learning rate was steeper for the Old condition, and the initial levels of performance were comparable between the two conditions.

In Session 2, conducted 1 week later, there was a main effect of condition, $F(1, 21) = 36.202$, $p < .0001$, and block, $F(7, 147) = 5.123$, $p < .0001$. Note that the main effect of condition was between Old displays and Repeated-New displays that were also repeated throughout the second session. Hence, the significant difference demonstrates long-term retention of Old displays while ruling out any effects of short-term learning within Session 2. The interaction between condition and block was not significant, $F(7, 147) = 2.136$, $p > .05$. This result is not surprising, given that the within-session learning effect was comparable in Session 2 between Old and Repeated-New. The main effect of condition is direct evidence for retention of contextual cuing of Session 1. Most impressively, the contextual cuing effect was significant in the first block of Session 2, $F(1, 21) = 14.94$, $p < .001$, suggesting that the long-term memory traces for spatial context were immediately available after a 1-week delay.

Because displays repeat in both conditions, we did not attempt to use power functions to model differential effects of learning within the second session. Finally, performance in the first block of Session 2 appears to be faster than the last block of Session 1. However, the improvement was not significant.

Explicit memory task. Even after two sessions of repeated exposure that produced significant contextual cuing, participants were unable to consciously associate spatial configurations with target locations. Mean performance for correctly guessing target locations in Old, Repeated-New, and New displays was 24.8%, 26.1%, and 23.4%, respectively. None of the pairwise comparisons was significant, and none of the recognition performance measures was significantly different from chance (25%), all ps > .20. All of the participants fell within the 95% confidence interval around 25% correct in all conditions.

Only 6 of 22 participants reported having noticed display repetitions, among whom only 1 reported having explicitly attempted to remember the repetition. These six aware participants were not able to guess on the Old condition (25%) and the Repeated-New condition (29%) any more accurately than the New condition (34%). ANOVA test using awareness and condition as factors showed that recognition was not affected by self-reported awareness, $F < 1$, *ns.* In addition, the aware and unaware participants showed no difference in their contextual cuing effect in Session 1 ($M = 132$ ms, $SE = 46$, for unaware participants; $M = 192$ ms, $SE = 42$ for aware participants, $p > .20$) or Session 2 ($M = 94$ ms, $SE = 21$, for unaware participants; and $M = 163$ ms, $SE = 39$ for aware participants, $p > .10$). These analyses indicate that aware participants were not truly aware of the nature of the implicit learning and memory that supports contextual cuing.

Discussion

Memory representations for spatial context lasted for at least 1 week, producing significant contextual cuing in the second session tested 1 week after initial learning. This suggests that contextual representations acquired incidentally in search tasks have a long,

durable time course. This is consistent with work on other forms of implicit learning, which support robust implicit memory traces over a long time (Cave, 1997; Cave & Squire, 1992; Gooding et al., 1994; Mitchell & Brown, 1988). In addition, this finding enhances the ecological significance of contextual cuing. If such arbitrary contextual representations in search tasks persist beyond the experimental session, it is likely that contextual representations formed outside the lab in the real environment would also have a durable time course to benefit everyday perception.

General Discussion

During visual search, spatial visual context information is encoded when it is predictive of the target location. Such contextual learning forms memory traces that facilitate search, a process called contextual cuing. Previous work suggested that this contextual cuing effect is driven by implicit memory representations (Chun, 2000; Chun & Jiang, 1998; Chun & Phelps, 1999). Participants performed at chance levels at discriminating novel displays from displays that were repeated throughout the experimental session. In addition, participants rarely reported an intention to memorize the repeated displays, suggesting that contextual information was learned incidentally.

This study provided new evidence that reinforces the claim that spatial contextual memory is implicit in the contextual cuing paradigm. Although past studies failed to detect explicit memory traces, the Old/New recognition task used in those studies taps memory traces (familiarity judgments) that may not be directly relevant for the search task, making it less than ideal for measuring potential explicit memory contributions. A more sensitive memory test should access processes that are likely to be used in visual search (Perruchet & Amorim, 1992; Shanks & St. John, 1994; Willingham et al., 1989). Thus, in this study, participants were asked to guess where they thought the target should appear given a target-absent display that presented either New or Old spatial configurations. Observers were not able to use Old context information to guess the target location. They performed at chance levels.

Our second experiment showed that awareness of the task manipulation and attention to the repeating global patterns did not benefit search or explicit memory performance. Thus, spatial contextual learning appears to occur in an implicit manner that is somewhat impenetrable from conscious influences (Curran & Keele, 1993; Frensch & Miner, 1994; Jacoby & Witherspoon, 1982; Jiménez et al., 1996; Tulving et al., 1982), at least when participants are performing a concurrent search task.

Finally, an important property of implicit memory traces is that they enjoy a long, durable time course (Cave, 1997; Cave & Squire, 1992; Mitchell & Brown, 1988; Schacter & Buckner, 1998; Wiggs & Martin, 1998). Our third experiment showed that implicit spatial context memory may last at least 1 week. This is remarkable when one considers the fact that the spatial layouts were defined by distractors to be rejected, in other words, as incidental context information. In addition, the spatial layouts were initially novel, highly similar to each other, and quite complex. Previous studies of long-term implicit memory have typically used common objects and words that were familiar and highly distinguishable from each other. In addition, previous studies typically presented the stimuli as the main task, assuring that attention was fully focused on them. These various features were absent in our con-

textual cuing task, yet memory traces formed in our task were still robust enough to last for at least 1 week.

The present findings are relevant for understanding the functions of different neural systems that underlie explicit and implicit memory. A predominant view of human memory systems has been that explicit memory depends on the hippocampal system and implicit memory depends on other nonhippocampal structures. However, Chun and Phelps (1999) showed that amnesic patients demonstrated no contextual cuing, indicating that contextual learning may depend on an intact hippocampus and medial temporal lobe system,[1] despite the implicit nature of the task. The present results strengthen this finding by providing additional evidence for the implicit nature of spatial contextual cuing. The deficit for implicit contextual cuing in Chun and Phelps's study stands in contrast to a number of studies that have revealed intact associative learning in amnesic patients using motor sequence learning, reading, or masked identification tasks (Curran, 1997; Gabrieli, Keane, Zarella, & Poldrack, 1997; Goshen-Gottstein & Moscovitch, 1995; Graf & Schacter, 1985; Mayes & Gooding, 1989; Moscovitch, 1994; Moscovitch, Winocur, & McLachlan, 1986; Musen & Squire, 1993; Nissen & Bullemer, 1987; Reber & Squire, 1994; Schacter & Graf, 1986; but see Cermack, Bleich, & Blackford, 1988; Shimamura & Squire, 1989). The discrepancy reflects the unique demands of contextual cuing, which requires encoding of (a) the complex configuration of multiple item locations to discriminate one spatial configuration from another and (b) the association of a configuration with an embedded target location. In contrast, prior studies of associative priming required learning of simple associations between one item and another. Only complex, configural learning or higher-order associative learning should depend on the hippocampus (Cohen & Eichenbaum, 1993; Hirsh, 1974; Kim & Fanselow, 1992; McClelland, McNaughton, & O'Reilly, 1995; Morris, Garrud, Rawlins, & O'Keefe, 1982; O'Keefe & Nadel, 1978; Phillips & LeDoux, 1992; Rudy & Sutherland, 1994). Accordingly, medial temporal lobe and hippocampal damage impaired learning of relational information in visual scenes (Gaffan, 1994; Murray, Baxter, & Gaffan, 1998; Ryan, Althoff, Whitlow, & Cohen, 2000) and higher-order associative information in sequence learning tasks (Curran, 1997). All these studies converge to show that simple associative learning is preserved while relational learning and higher-order associative learning is disrupted with hippocampal and medial temporal lobe damage. Thus, the hippocampus and medial temporal lobe may be important for configural, relational encoding, independent of awareness. Such configural coding subserves the ability to form explicit, episodic memories that can be consciously accessed (Cohen & Eichenbaum, 1993; Moscovitch, 1994; Squire, 1992), as well as implicit representations of relational information.

Although this study provided further evidence of the implicit nature of the contextual cuing task, we caution that this conclusion is bounded by the experimental parameters employed here. In other words, it is likely that increasing the amount of training and reducing the number of different displays will allow Old repetitions to be consciously accessible. For example, in SRT tasks, increased training increases awareness of the structure of the stimuli (Perruchet & Amorim, 1992; Willingham et al., 1989). This does not pose a serious problem from our perspective. In the real world, it is clear that observers have the capacity to consciously discriminate experienced versus novel scenes. Our emphasis is simply that awareness is not necessary because contextual cuing effects can be observed even before awareness contributes to recognition and performance. The present study may further bolster the contextual cuing paradigm as a useful vehicle for studying the role of awareness in learning and memory (Stadler & Frensch, 1998).

Finally, going beyond issues of memory, our findings underscore the ecological utility of the contextual cuing paradigm for issues in vision. This line of research highlights the importance of learning and memory mechanisms in perceptual processing. The visual world contains many regularities, forming an invariant structure that is stable over time. For example, the configurations of buildings in one's environment or dials and lights on an instrumentation panel are generally stable from moment to moment, day to day. These regularities are presented in the form of visual context, so it is useful to encode such invariant information and use it in subsequent acts of perception (Chun, 2000; Chun & Jiang, 1998, 1999; Chun & Nakayama, 2000; Jiang & Chun, 2001; Olson & Chun, 2001, 2002). The present results indicate that memory for complex artificial scenes lasts for a durable length of time, so we propose that regularities in the everyday visual environment also form long-lasting impressions within the minds of observers.

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[1] In our discussion of functional anatomy, we must emphasize that the neural substrate of implicit spatial contextual learning requires further specification. Chun and Phelps (1999) tested patients with medial temporal lobe damage that included the hippocampus but also extended beyond the hippocampus. Manns and Squire (2001) replicated this contextual cuing impairment in several additional patients (including Patient E. P.) with medial temporal lobe damage that included the hippocampus and also temporal lobe structures outside the medial temporal lobe. In addition, Manns and Squire demonstrated that contextual cuing was preserved in other amnesic patients with damage restricted to the hippocampus proper, but the atrophy was only partial. These two studies suggest that more extensive damage of the hippocampus is necessary or that additional structures in the medial temporal lobe or even outside the medial temporal lobe memory system are necessary for contextual learning. Possible heterogeneity of function across different structures within the medial temporal lobe further complicate the story. The functional neuroanatomy will be difficult to resolve with human lesion data alone because it is rare to find patients with complete damage restricted to the hippocampus or other medial temporal lobe structures. Functional neuroimaging data should prove informative, and it is worth noting that at least one neuroimaging study revealed hippocampal involvement in normal participants performing the contextual cuing task (Preston, Salidis, & Gabrieli, 2001). To fully establish the necessity of an anatomical region for contextual learning, carefully conducted nonhuman primate lesion studies may prove most insightful.

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