Research Article

AMNESIA IS A DEFICIT IN RELATIONAL MEMORY

Jennifer D. Ryan, Robert R. Althoff, Stephen Whitlow, and Neal J. Cohen
University of Illinois at Urbana-Champaign

Abstract—*Eye movements were monitored to assess memory for scenes indirectly (implicitly). Two eye movement–based memory phenomena were observed: (a) the* repetition effect, *a decrease in sampling of previously viewed scenes compared with new scenes, reflecting memory for those scenes, and (b) the* relational manipulation effect, *an increase in viewing of the regions where manipulations of relations among scene elements had occurred. In normal control subjects, the relational manipulation effect was expressed only in the absence of explicit awareness of the scene manipulations. Thus, memory representations of scenes contain information about relations among elements of the scenes, at least some of which is not accessible to verbal report. But amnesic patients with severe memory impairment failed to show the relational manipulation effect. Their failure to show any demonstrable memory for relations among the constituent elements of scenes suggests that amnesia involves a fundamental deficit in relational (declarative) memory processing.*

In recent work, we have shown that eye movements may be used as an indirect (implicit) measure of memory, revealing on-line changes in the processing of a stimulus as a result of prior exposure. In moving their eyes around a visual display, fixating (i.e., sampling with their eyes) various regions of the display, subjects make fewer fixations and sample fewer regions for previously viewed items than for novel items (Althoff & Cohen, 1999; Althoff et al., 1998), an effect of repetition we have termed the *eye movement–based memory effect* (Althoff & Cohen, 1999). This effect occurs independently of explicit remembering or conscious awareness of which items have been seen previously, and is exhibited even by amnesic patients (Althoff & Cohen, 2000).

In the experiments reported here, we examined memory for scenes. Although eye movements during scene viewing can be related to such physical aspects of a scene as luminance and texture, previous work has shown the importance of semantic knowledge that viewers bring to the session (Henderson, Weeks, & Hollingworth, 1999; Loftus & Mackworth, 1978; Parker, 1978), as illustrated nicely by findings of increased viewing of objects that are semantically anomalous in the context of a given scene (Henderson et al., 1999; Loftus & Mackworth, 1978). Other work, most notably by Stark and colleagues (Noton & Stark, 1971; Stark & Ellis, 1981) and by Parker (1978), has suggested that repetition of scenes may cause more stereotypic patterns of viewing than found with the first viewing; specifically, repetition may result in less random transitions among successive fixations (also see Yarbus, 1967; but see Althoff, 1998).

In the present experiments, we applied our eye movement measures of repetition to the viewing of scenes, and also used a new set of eye movement measures of memory for relations among the elements of scenes. Subjects saw some scenes once, some scenes three times, and others initially in one form and then in a manipulated version, in which some relations among the constituent elements of the scenes had been altered. The effects of memory for scenes were revealed in measures distinguishing viewing of novel versus repeated or manipulated scenes; the effects of memory for relations among elements of scenes were revealed in measures distinguishing viewing of manipulated versus repeated or novel scenes.

This approach permitted us to explore more thoroughly the nature of long-term memory representations of scenes. It provides a different perspective than behavioral assessment, for example, having subjects explicitly detect scene changes (McConkie & Currie, 1996; Simons & Levin, 1998). In addition, it offers a powerful way to address difficult questions about declarative memory, conscious awareness, and human amnesia. One prominent view of amnesia holds that it is a selective deficit of declarative memory (Cohen & Eichenbaum, 1993; Eichenbaum, 1997, 1999; Squire, 1992). This account emphasizes memory for the relations among the constituent elements of scenes or events (*relational memory binding*; Cohen et al., 1999). The major alternative view of amnesia holds that it is a selective deficit of explicit memory (Graf & Schacter, 1985; Schacter, 1987), emphasizing conscious access to or conscious awareness of representations of previous learning experiences.

As frequently reported, amnesic patients show deficits in recall or recognition, involving direct (explicit) tests of memory, but normal priming (or repetition effects) on indirect (implicit) tests of memory (e.g., Gabrieli, 1998; Richardson-Klavehn & Bjork, 1988; Schacter, 1987; Tulving & Schacter, 1990). But note that any direct (explicit) memory test also involves declarative memory for relations. Such tests require, by definition, the ability to gain conscious access to the prior learning episode associated with the test item, thereby requiring memory for some relation between the to-be-tested item and the context or prior learning experience in which it occurred. Thus, any deficit on a direct (explicit) memory test, as is seen in amnesia, could reflect a deficit of explicit memory or of relational memory or of both. In the present work, involving indirect (implicit) assessment of memory, any selective deficit in memory for relations among the elements of scenes observed in amnesia can be attributed to relational (declarative) memory and not explicit memory.

EXPERIMENT 1

Method

Subjects

Twenty-four college-aged subjects from the University of Illinois at Urbana-Champaign participated in exchange for payment.

Stimuli and design

Subjects were presented with color images of real-world scenes on a 21-in. color monitor. Each picture measured 756 × 486 pixels, subtending approximately 14° × 11° of visual angle 40 in. from the moni-

Address correspondence to Neal J. Cohen, Amnesia Research Laboratory, Beckman Institute, University of Illinois, 405 N. Mathews, Urbana, IL 61801; e-mail: n-cohen@uiuc.edu.

tor. There were three types of scenes: (a) *novel* scenes, seen once during the experiment; (b) *repeated* scenes, seen once in each of the three blocks of the experiment; and (c) *manipulated* scenes, seen once in each of the first two blocks, in original form, and then seen in manipulated form in the final (critical) block.

Every scene had an unmanipulated and a manipulated version so that any scene could be assigned to any of the three scene types; each version of each scene was rotated across subjects, so that each was viewed equally often as novel, repeated, or manipulated. Manipulated versions of the scenes involved changes in the relations among some elements of the scenes. The types of manipulations were (a) addition of a new object, (b) deletion of an object, or (c) left-right shifting of an object. There were equal numbers of the manipulation types.

Eye movements during the final (critical) block were examined. Specifically, eye movements of subjects viewing a given scene as manipulated were compared with eye movements of subjects viewing the same scene as novel or repeated. Thus, the eye movement results reported are for the same scenes differing only in their viewing history (as illustrated in Fig. 1): The same scene was a novel scene if it was being viewed for the first time, a repeated scene if it was being viewed in the same form for the third time, and a manipulated scene if it was being viewed for the first time in a new form after having been viewed twice previously with different relations among the constituent elements of the scene.

Each scene had a corresponding yes/no question directing subjects to particular relations among the objects in the scene that might later be manipulated (e.g., for the scene shown in Fig. 1: "Are there any girls next to the bridge?"). The correct answer was equally often "yes" or "no" within each block for each scene type.

Procedure

On each trial, a scene was presented for 5 s. The subject's task was to answer the question about the scene, pressing one button for "yes" and another for "no." First there were two study blocks, each involving 24 scenes: 8 novel scenes, 8 repeated scenes, and 8 manipulated scenes in their original form. Then, in the final (critical) block, subjects saw 16 more novel scenes, the same 8 repeated scenes, and the manipulated versions of the 8 manipulated scenes. A short break (1–3 min) was provided between blocks. Written informed consent was obtained before testing, and written debriefing was provided upon completion.

Eye movements were monitored during viewing of each scene with an Applied Science Laboratories 4250R remote eyetracker. This camera-based system illuminates the eye with infrared light, captures an image of the pupil, and records the location of the center of the pupil and the reflection of the infrared light off the cornea. The angle between the center of the pupil and the corneal reflection changes as the eyes move, permitting eye position to be monitored. Eye movement data were transformed from *x*, *y* coordinates into a data matrix indicating the location, timing, and duration of each eye movement. Calculations were performed on these data using an automated software package (EMTool) created by our laboratory.

Data analysis

Two sets of measures were derived to characterize eye movement behavior during viewing. Changes in viewing reflecting some aspect of memory for previous exposure to specific scenes—a *repetition effect*—were determined by differences between previously viewed (repeated and manipulated) scenes and novel scenes. We used two eye

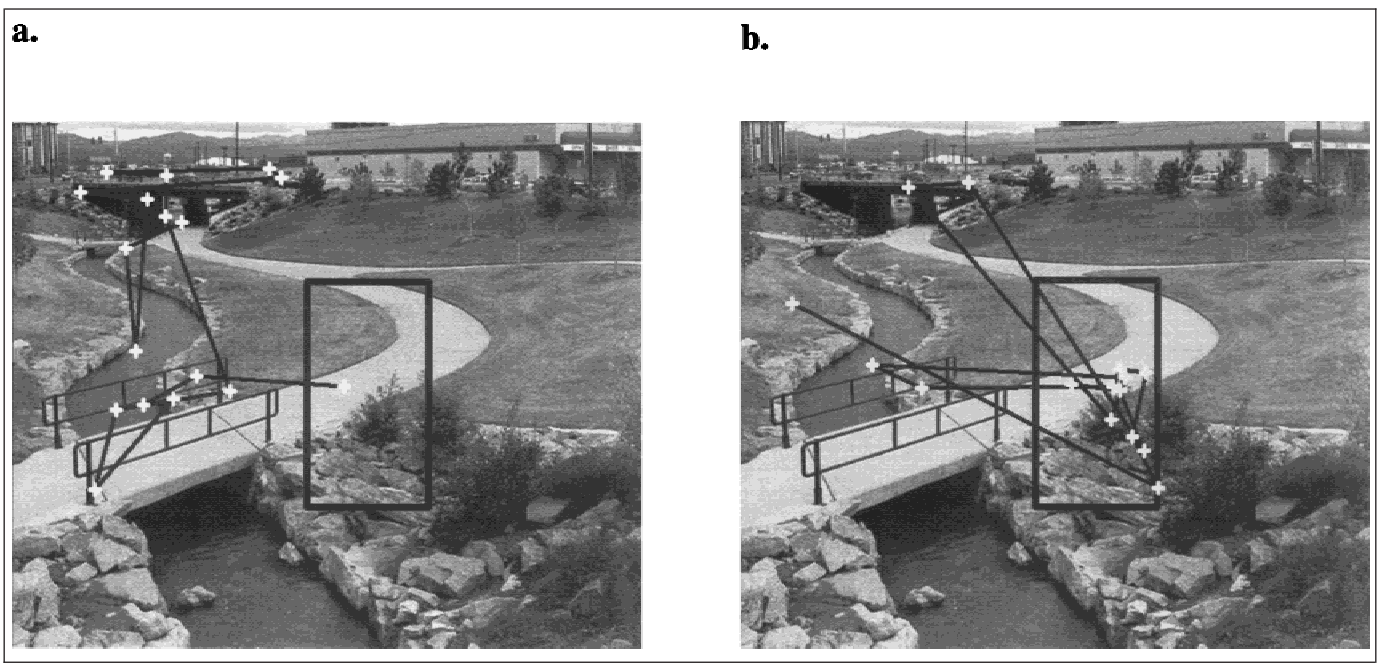

Fig. 1. Example scene illustrating the relational manipulation effect. Eye movements (black lines) and fixations (white crosses) for 2 subjects are shown superimposed on the same scene with different viewing histories. A typical-sized critical region is outlined in the box. When the scene was viewed as a repeated scene (a), it was always presented in the same form, and the critical region was always empty of people. Few eye fixations were attracted there. When the scene was viewed as a manipulated scene (b), two girls were in the critical region during study but were removed in the critical block. Although empty in the final block, the critical region attracted many fixations.

movement measures that had shown a repetition effect in viewing of faces in our previous work (Althoff & Cohen, 1999; Althoff et al., 1998): *number of fixations* (given the fixed viewing time, this measure was inversely proportional to fixation duration) and *number of regions sampled*.

Changes in viewing reflecting some aspect of memory for relations among elements of a scene were determined by differences in eye movements between manipulated scenes and unmanipulated (novel and repeated) scenes. In line with the work cited earlier reporting increased viewing of objects semantically inconsistent with the scene in which they appear, we assessed viewing of the critical region in which the manipulation would occur (for the manipulated version of that scene; e.g., the region from which the girls were deleted in Fig. 1). Each scene had a critical region designated. We measured the *proportion of fixations* directed to the critical region, *number of transitions* to or from the critical region, *proportion of viewing time* in the critical region, and *duration of first gaze* into the critical region. Increased viewing of the critical region for scenes that had been manipulated compared with the same scenes when unmanipulated would constitute a *relational manipulation effect*, indicating memory for relations among (at least the manipulated) elements of the scene. Particularly strong evidence of relational memory would come from a finding of increased viewing of regions that became empty of objects because of the scene manipulation. This would constitute strong evidence because eye movements tend to be attracted to objects and not empty regions; increased viewing of regions that became empty therefore seems best attributed to memory for what used to be there.

Results and Discussion

A repetition effect was observed: Subjects made fewer fixations and sampled fewer regions in viewing repeated and manipulated scenes compared with novel scenes. Specifically, direct comparisons for data from the final block showed a significant effect of picture type for both number of fixations, $ts(46) = 3.04$ and 2.33, $ps < .05$, and number of regions sampled, $ts(46) = 1.99$ and 3.63, $ps < .05$ (see Fig. 2). In addition, there was a significant block-by-picture-type interaction for both number of fixations, $F(4, 92) = 4.28$, $p < .01$, and number of regions sampled, $F(4, 92) = 4.67$, $p < .01$. Thus, repetition of scenes resulted in less eye movement sampling upon subsequent viewing, just as we had observed in previous work with faces (Althoff & Cohen, 2000; Althoff et al., 1998).

The second effect observed was a relational manipulation effect: Subjects directed a higher proportion of their total fixations (see Fig. 3) and dedicated a higher proportion of their total viewing (fixation) time to the critical region for manipulated scenes compared with repeated or novel scenes. Direct comparisons from the final block showed a significant effect of picture type on proportion of fixations, $ts(46) = 7.41$ and 7.03, $ps = .0001$, and proportion of time, $ts(46) = 5.44$ and 5.95, $ps = .0001$. There was also a significant block-by-picture-type interaction for proportion of fixations, $F(4, 92) = 12.44$, $p < .001$, and proportion of time, $F(4, 92) = 6.93$, $p = .0001$. Duration of first gaze into the critical region did not differ reliably across types of pictures in this experiment, $F(2, 46) < 1$, nor in the subsequent experiments, but subjects made more transitions into and out of the critical region for manipulated than for repeated or novel scenes. Direct comparisons for the final block showed a simple effect of picture type, $ts(46) = 2.01$ and 1.72, $ps < .05$ and .09 (see Fig. 3), and there was a significant block-by-picture-type interaction, $F(4, 92) = 2.97$, $p < .05$. Thus, changes in the relations among elements of previously viewed scenes caused the eyes to be directed disproportionately to and resulted in increased viewing of the very regions where changes had occurred (as illustrated in Fig. 1). This relational manipulation effect demonstrates memory for the relations among the constituent elements of scenes.

EXPERIMENT 2

The procedure used in Experiment 1 directed subjects' attention to the relations that might ultimately be manipulated. Are such orienting questions necessary in order for a relational manipulation effect to occur? Do scene representations include relational information even

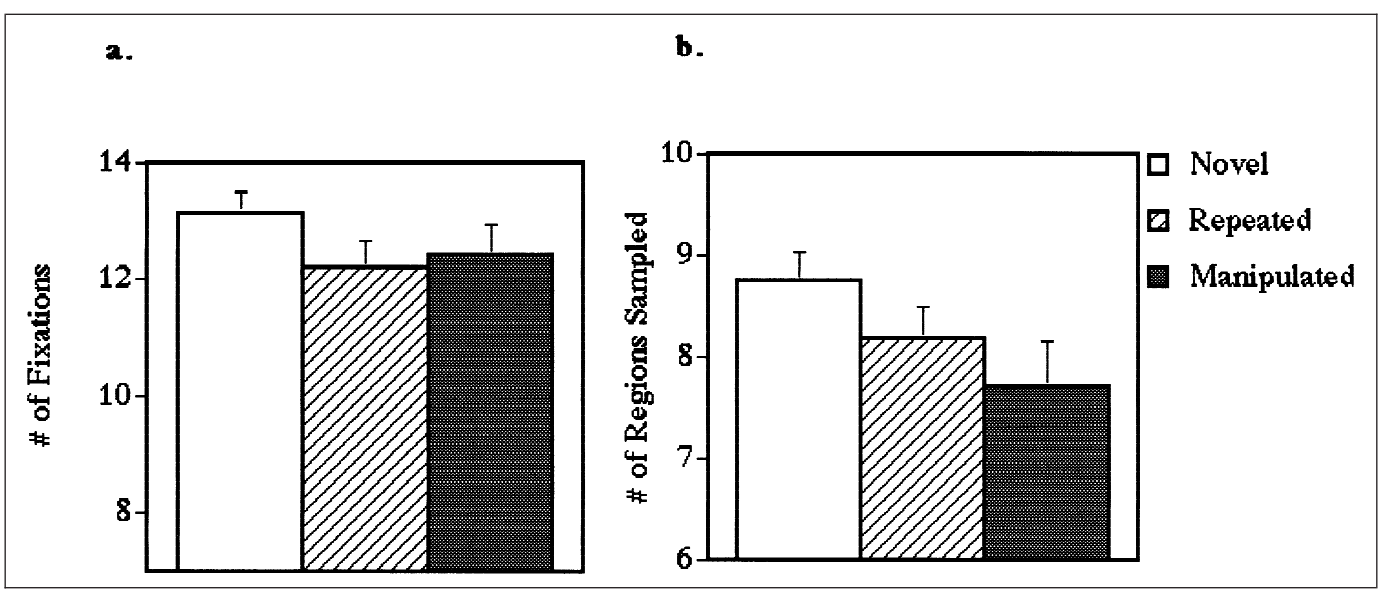

Fig. 2. Measures of the repetition effect: number of fixations (a) and number of regions sampled (b) for novel, repeated, and manipulated scenes in the final block in Experiment 1.

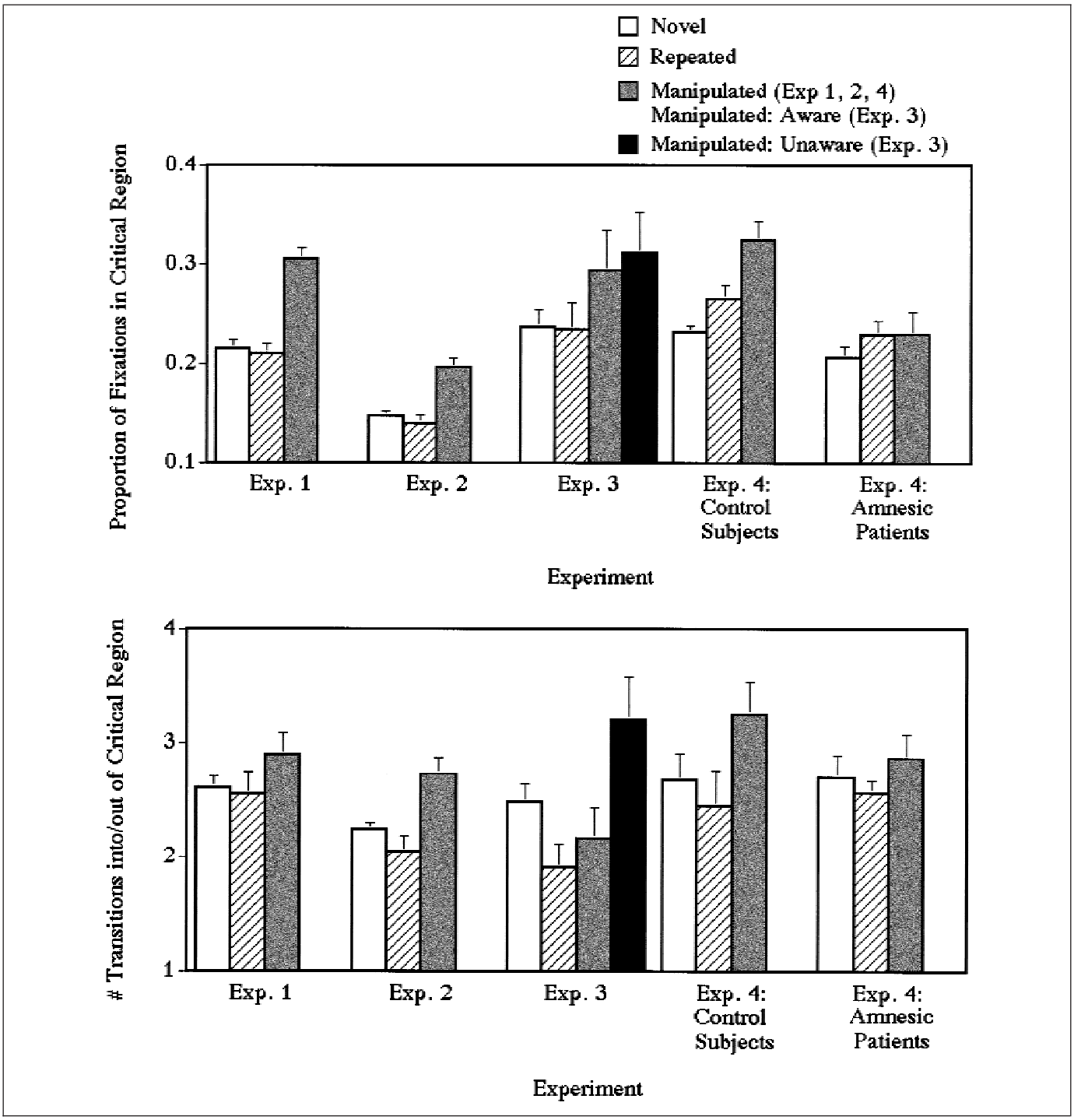

Fig. 3. Measures of the relational manipulation effect: proportion of fixations in the critical region (top panel) and number of transitions into and out of the critical region (bottom panel) for novel, repeated, and manipulated scenes in the final block in Experiments 1 through 4. For Experiment 3, results are shown separately for subjects who were aware and unaware that scene manipulations had occurred.

in free-viewing conditions? In this experiment, we eliminated the yes/no orienting questions previously associated with the scenes, testing whether the relational manipulation effect could be observed in free viewing when subjects had no forewarning about the relations to which they should attend.

Method

Twenty-four college-aged subjects from the University of Illinois at Urbana-Champaign participated in exchange for payment. The materials and procedure were the same as in Experiment 1, except that

there were no questions presented with the scenes and subjects were instructed only to study the scenes for a later memory test.

Results and Discussion

As shown in Figure 3, the relational manipulation effect was elicited in free-viewing conditions even without the presence of orienting yes/no questions. Viewing of manipulated scenes differed from viewing of repeated and novel scenes in that the critical region received a higher proportion of total fixations, $ts(46) = 5.18$ and 4.54, $ps = .0001$, and a greater number of transitions into and out of the region, $ts(46) = 4.82$ and 3.47, $ps < .002$. In addition, the critical region received a higher proportion of total viewing (fixation) time in manipulated scenes than in other scenes, $ts(46) = 3.69$ and 3.20, $ps < .003$.

The data indicate that subjects directed their viewing to the critical region, overall, less in this experiment than in Experiment 1. It seems that the yes/no orienting questions, present only in Experiment 1, may have increased viewing of the critical region. But the effect of having orienting questions was equally evident for the novel, repeated, and manipulated scenes; it had no impact on the relational manipulation effect, as reflected in the nonsignificant interaction of block by picture type by experiment, $F(4, 184) = 1.61$, $p > .15$. The presence of the relational manipulation effect in Experiment 2 indicates that long-term representations of scenes include relational information even in free-viewing conditions.

EXPERIMENT 3

To this point, we have assumed these eye movement–based memory effects to be implicit memory phenomena. They were observed under indirect (implicit) test conditions: Subjects were not asked which scenes they remembered, and the eye movements sampled were not the intentional responses of the subjects. In addition, we had previously demonstrated a normal repetition effect for faces in amnesic patients with severe deficits in explicit remembering (Althoff & Cohen, 2000). But what about the relational manipulation effect? Might it be sensitive to or dependent on explicit awareness of the manipulations? The relationship between the relational manipulation effect and explicit awareness was tested in Experiment 3.

In this experiment, subjects saw the critical block a second time; during this fourth block, they explicitly judged whether or not a manipulation had occurred in each scene. The eye data were then sorted according to subjects' explicit awareness of the scene manipulations, permitting us to determine the role of explicit awareness in producing the relational manipulation effect. Subjects made explicit judgments during a repeated viewing of the critical block, after the eye movement data were collected, so as to avoid any contamination of the eye movement effects that could occur by imposing direct (explicit) memory demands on the task. In other work (Ryan & Cohen, 2000), we have demonstrated that having subjects make explicit memory judgments changes the nature of their eye movement search, resulting in different eye movement patterns. Accordingly, in Experiment 3, we collected eye movement data under indirect (implicit) conditions, as in Experiments 1 and 2, making it possible to compare the results of all three experiments.

Method

Twelve college-aged students from the University of Illinois at Urbana-Champaign participated in exchange for payment. The materials and procedure were the same as in Experiment 1 except for the addition of a fourth block, which was a repeated viewing of the critical block. At the beginning of the fourth block, subjects were informed that the previous block had contained scenes that were either novel, repeated, or manipulated, and their task now was to identify the manipulated scenes and to specify the nature of the manipulation (e.g., "the girls were removed"). Only subjects who could specify the nature of the manipulation were considered "aware" of the manipulation.

Results and Discussion

For 57% of the manipulated scenes, subjects both correctly identified that there was a manipulation and correctly specified the nature of the manipulation, thus achieving a relatively high level of performance (cf. results in the "change blindness" literature). Presumably performance was aided by the orienting questions that guided subjects to the critical relationships. For each subject, scenes were sorted into those for which the subject had explicit awareness of the manipulation and those for which the subject did not have explicit awareness of the manipulation. These data were accumulated across all subjects for analyses. The results for two measures of viewing of the critical regions are shown in Figure 3.

An analysis of the data collapsed across aware and unaware subjects showed that the critical regions of manipulated scenes received a higher proportion of total fixations, $ts(22) = 3.03$ and 3.14, $ps < .01$, and a higher proportion of total viewing (fixation) time, $ts(22) = 2.28$ and 2.11, $ps < .05$, than the same regions in repeated and novel scenes. Thus, the relational manipulation effect was again replicated. But the effect was not seen on any of the measures for those manipulated scenes for which subjects were explicitly aware of the manipulation: proportion of fixations, $t(150) = 1.35$ and $t(245) = 1.43$; proportion of time, $t(150) = 1.20$ and $t(245) = 1.22$; number of transitions, $t(150) < 1$ and $t(245) < 1$; all $ps > .15$. Instead, the relational manipulation effect was exhibited only in the absence of explicit awareness: As can be seen in Figure 3, the critical regions of manipulated scenes for which subjects were unaware of the manipulation received a greater number of transitions into and out of the region than did the same regions in repeated or novel scenes or manipulated scenes that subjects were aware were manipulated, $t(134) = 3.13$, $p < .005$; $t(229) = 1.9$, $p < .058$; $t(94) = 2.29$, $p < .03$. For this variable, then, the relational manipulation effect occurred only in the absence of explicit awareness of the manipulations.

EXPERIMENT 4

The results from Experiment 3 demonstrate that the relational manipulation effect is not driven by explicit awareness of the manipulations; for no variables was there more viewing of the critical region in manipulated scenes than in unmanipulated scenes if viewers were explicitly aware of the manipulation. Rather, the eyes were directed to the critical region of a manipulated scene only when subjects were unaware of the manipulation. Accordingly, this paradigm has proven capable of providing an indirect (implicit) assessment of memory for relations in scenes. In Experiment 4, we used the paradigm to test the view (Cohen & Eichenbaum, 1993; Cohen et al., 1999; Eichenbaum,

1997) that amnesia reflects a deficit in memory for relations among the constituent elements of a scene (or event)—that is, that amnesia reflects a deficit in relational memory binding, rather than a deficit in explicit memory or conscious awareness.

Method

Six amnesic patients and 12 neurologically intact control subjects participated in return for payment. The etiologies of amnesia included closed head injury (A.K., D.D.), anoxia (M.M.), and rupture and surgical repair of an anterior communicating artery aneurysm (J.P.S., M.F., S.D.). All patients had significant memory impairment on standardized tests of memory: On the Wechsler Memory Scale–Revised, their mean overall score was 72.2 and their mean delayed recall score was 54.5 (2 and 3 standard deviations, respectively, below population norms). The control subjects were matched to the patients for age (44.3 for control subjects vs. 46.5 for patients; $p > .55$), education (15.8 vs. 15.7; $p > .9$), and full-scale IQ scores (120.3 vs. 108.6; $p > .1$). Each patient was tested twice, with the second session occurring after a delay of at least 3 months to minimize holdover effects; no difference in performance on any measure was seen across sessions (ps > .25). Control subjects were tested once each.

The materials and procedure were the same as in Experiment 1. The yes/no orienting questions were used to keep the amnesic patients on task and to ensure that they encoded the relations within the scenes.

Results and Discussion

A repetition effect was again observed: Across all subjects, there were fewer fixations and fewer regions sampled for repeated than novel scenes, Fs(1, 22) = 17.56 and 10.05, ps < .005. As can be seen in Figure 4, there was no difference in the magnitude of the repetition effect for the patient versus control groups (for the two measures, Fs[1, 22] < 1, ps > .6).

Control subjects exhibited, in addition, a relational manipulation effect, as can be seen in Figure 3. For manipulated scenes compared with repeated or novel scenes, the critical region received a greater proportion of fixations, ts(22) = 2.91 and 4.61, ps < .01; a greater number of transitions to and from the region, ts(22) = 2.44 and 1.74, ps < .03 and < .09; and (not shown) a higher proportion of viewing (fixation) time, ts(22) = 2.36 and 4.22, ps < .03.

By contrast, there was no relational manipulation effect in the amnesic patients. They showed no difference among picture types for any of the measures (main effect of picture type: Fs[2, 22] < 1, ps > .5), thereby producing an interaction that distinguished between the subject groups for proportion of fixations, $F(2, 44) = 3.36$, $p < .05$, and, marginally, proportion of viewing (fixation) time, $F(2, 44) = 2.68$, $p < .08$. None of the patients showed a relational manipulation effect.

GENERAL DISCUSSION

Two distinct eye movement–based memory phenomena were revealed during viewing of scenes: a repetition effect and a relational manipulation effect. The repetition effect was manifested as a decrease in sampling of previously viewed scenes compared with new scenes, just as in our work with faces (Althoff & Cohen, 1999; Althoff et al., 1998; Ryan & Cohen, 2000). Providing an indirect (implicit) measure of memory for previous occurrence, the repetition effect was intact in amnesic patients with severe deficits of explicit remember-

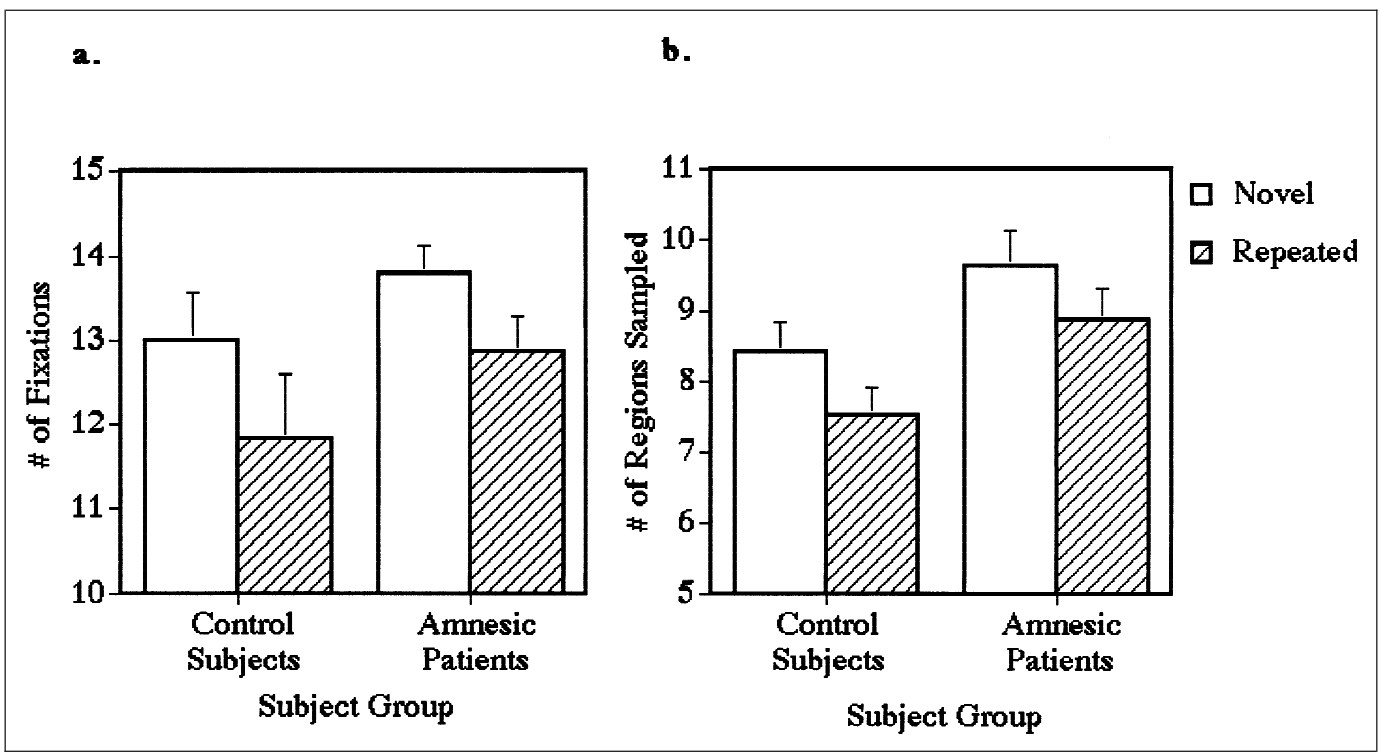

Fig. 4. Measures of the repetition effect: number of fixations (a) and number of regions sampled (b) for novel and repeated scenes in the final block in Experiment 4. Results are shown separately for amnesic patients and control subjects.

ing. By contrast with other indirect measures of memory in the literature, which show repetition priming effects as increases in speed or accuracy for repeated items, in this case prior exposure resulted in a change in how viewers extracted information from previously viewed scenes.

The relational manipulation effect was exhibited as increased viewing of the regions where manipulations of relations among scene elements had occurred. This effect was observed in four different experiments, when subjects were directed to encode certain relations in the original scenes and also when subjects were given free-viewing instructions. This eye movement effect reveals memory for relations among the constituent elements of the originally studied scenes—either object-location relations (e.g., in Fig. 1, girls had been in the lower right-hand corner of the scene) or relations between objects (girls had been just behind the bridge).

When subjects explicitly judged whether manipulations had occurred, the data showed that the relational manipulation effect did not require explicit awareness of the manipulations. Indeed, the effect was expressed only in the absence of awareness. To our knowledge, this is the first demonstration of a memory phenomenon with such constraints. By contrast, repetition priming can occur whether or not there is explicit remembering, not only in the absence of explicit remembering.

The finding that manipulated scenes elicited increased viewing directed to the very regions where the manipulations had occurred contrasts strikingly with reports of change blindness, in which subjects asked to explicitly detect changes in visual displays during ongoing viewing perform surprisingly poorly (e.g., Levin & Simons, 1997; Simons & Levin, 1998). There are various differences between these paradigms, but perhaps most important is that the relational manipulation effect does not depend on subjects' explicit reports about changes in the scenes; in fact, our effect was expressed only in the absence of explicit awareness of changes, a fact that underscores the importance of having alternative (nonbehavioral) measures. The current results indicate that memory representations of scenes contain information, not accessible to verbal report, about the relations among the elements of the scenes.

The finding that the relational manipulation effect depends on processes distinct from those supporting explicit remembering or conscious awareness, taken together with the finding that amnesic patients fail selectively to show the relational manipulation effect, helps clarify the nature of amnesia. The current data, together with reports of a deficit in amnesia for indirectly (implicitly) assessed memory for word-definition relationships (Gabrieli, Cohen, & Corkin, 1988), word pairings (Graf & Schacter, 1985), and cue-context relationships (Chun & Phelps, 1999), indicate that the memory system damaged in amnesia is not the same as explicit memory or conscious memory (cf. Clark & Squire, 1998). Rather, the memory system damaged in amnesia is declarative memory for relations among the constituent elements of scenes or events—relational memory binding of all manner of relations (Cohen & Eichenbaum, 1993; Cohen et al., 1999; Eichenbaum, 1997, 1999). Successful performance on explicit memory tests requires declarative memory of the relationship between the to-be-tested item and the learning experience, causing overlap of declarative memory and explicit or conscious memory, as noted earlier. But the converse is not true; declarative memory of the relations among the constituent elements of a scene or event does not require an explicit, conscious process. The current results document that even when explicit, conscious memory is made irrelevant or harmful to the critical performance measures, amnesic patients show impaired declarative memory for relations among the constituent elements of scenes.

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