# Awareness of what is learned as a characteristic of hippocampus-dependent memory

**Christine N. Smith**[a,b,1] **and Larry R. Squire**[a,b,c,d,1]

[a]Veterans Affairs San Diego Healthcare System, San Diego, CA 92161; [b]Department of Psychiatry, University of California, San Diego, La Jolla, CA 92093; [c]Department of Neurosciences, University of California, San Diego, La Jolla, CA 92093; and [d]Department of Psychology, University of California, San Diego, La Jolla, CA 92093

Contributed by Larry R. Squire, October 10, 2018 (sent for review August 28, 2018; reviewed by Elizabeth Kensinger and Ken A. Paller)

**We explored the relationship between memory performance and conscious knowledge (or awareness) of what has been learned in memory-impaired patients with hippocampal lesions or larger medial temporal lesions. Participants viewed familiar scenes or familiar scenes where a change had been introduced. Patients identified many fewer of the changes than controls. Across all of the scenes, controls preferentially directed their gaze toward the regions that had been changed whenever they had what we term robust knowledge about the change: They could identify that a change occurred, report what had changed, and indicate where the change occurred. Preferential looking did not occur when they were unaware of the change or had only partial knowledge about it. The patients, overall, did not direct their gaze toward the regions that had been changed, but on the few occasions when they had robust knowledge about the change they (like controls) did exhibit this effect. Patients did not exhibit this effect when they were unaware of the change or had partial knowledge. The findings support the idea that awareness of what has been learned is a key feature of hippocampus-dependent memory.**

declarative memory | medial temporal lobe | eye movements | amnesia

Declarative memory refers to the capacity to recollect information about past facts and events and depends on the integrity of the hippocampus and related medial temporal lobe (MTL) structures (1, 2). Nondeclarative memory refers to skill and habit learning, the phenomenon of priming, and other forms of experience-dependent behavior that are expressed through performance rather than recollection. These forms of memory are spared after MTL damage (3, 4). Declarative memory is thought to be accompanied by conscious knowledge (or awareness) of what has been learned, and the availability of conscious awareness has been considered one of its key features (5–7). In this view, the MTL is a brain system supporting the acquisition of conscious memory. An alternative view emphasizes the nature of the task and a task's processing requirements rather than the presence or absence of conscious knowledge as an important factor determining whether learning depends on the MTL (8). For example, it has been suggested that the MTL is needed when performance depends on the learning of associations or relations between items, regardless of whether individuals are aware or unaware of what they have learned (8–10).

Eye movements that one makes in response to visually presented material depend on one's prior experience with the material (11). These experience-dependent eye movements provide a fruitful way to explore the links between performance, conscious memory, and MTL function. One phenomenon of interest is the manipulation effect. The finding is that individuals spend more time viewing the region of a familiar scene where a change has been introduced than they spend viewing a matched region of a familiar scene that has not been changed (12).

A critical question is whether the manipulation effect reflects conscious recollection or whether eye movements in this instance reflect an automatic response that is independent of conscious recollection. In three experiments (ref. 13, Experiment 1, $n = 20$; ref. 13, Experiment 2, $n = 20$; ref. 14, Experiment 2, $n = 51$), the manipulation effect was observed only when healthy participants had conscious knowledge about the manipulation. Specifically, the manipulation effect occurred only when they identified the scene as changed and also described correctly what had changed. Intermediate cases of what one might term partial knowledge did not support the manipulation effect (14). Participants with partial knowledge were participants who identified the scene as changed but could not describe the change, or participants who did not identify the scene as changed but then correctly described the change after being informed that a change had occurred.

While the importance of having conscious knowledge about the manipulation has been well demonstrated (13, 14), the role of the MTL in the manipulation effect as well as the relationship between the MTL and knowledge about the manipulation is not understood. One possibility is that patients with MTL lesions will usually fail to exhibit the manipulation effect, and whether or not they exhibit the effect on a particular trial will be unrelated to awareness about the manipulation. Another possibility is that awareness or unawareness of the manipulation is an important factor for understanding the role of the MTL. Although patients would not be expected to exhibit the manipulation effect or to be aware of the manipulation on most trials. Nevertheless, on the few occasions when they have robust knowledge of the manipulation, they might exhibit the effect. We tested these two hypotheses by examining the relationship between the manipulation effect and awareness of the manipulation in patients with MTL damage and controls.

## Results

**Memory Performance, Confidence Ratings, and Awareness.** The patients were markedly impaired at discriminating in block 3 between the 24 manipulated scenes and the 24 repeated scenes (Figs. 1 and 2*A*; $t[9] = 5.1$, $P < 0.001$, two-sample $t$ test). Controls correctly identified a mean of 16.5 of the manipulated scenes and

### Significance

**Knowledge (or awareness) of what has been learned has been described as a key feature of hippocampus-dependent memory or as unhelpful for understanding hippocampal function. We recorded eye movements while memory-impaired patients with hippocampal lesions and controls viewed familiar scenes or familiar scenes that had been altered. Controls preferentially looked at the altered regions of the scenes, but only when they knew what had changed and where the change occurred. Patients had difficulty distinguishing altered and unaltered scenes and, overall, did not direct their viewing toward the altered regions. Nonetheless, they did exhibit this effect on the few occasions when they were aware of the change. The results indicate the importance of conscious awareness for understanding hippocampal function.**

Author contributions: C.N.S. and L.R.S. designed research; C.N.S. performed research; C.N.S. analyzed data; and C.N.S. and L.R.S. wrote the paper.

Reviewers: E.K., Boston College; and K.A.P., Northwestern University.

The authors declare no conflict of interest.



[1]To whom correspondence may be addressed. Email: cnsmith@ucsd.edu or lsquire@ucsd.edu.

Published online November 5, 2018.

20.5 of the repeated scenes (for patients, 8.4 and 18.4, respectively). Patients also differed from controls with respect to the confidence ratings associated with their correct and incorrect choices (Fig. 2*B*). While controls exhibited higher confidence for correct responses than for incorrect responses ($t[5] = 2.8$, $P = 0.037$, paired *t* test), the patients did not ($t[4] = 1.0$, $P = 0.361$, paired *t* test).

Next, we calculated the percentage of the 24 scenes for which participants were designated as aware, as unaware, or as having intermediate knowledge of the manipulation (Fig. 3). The patients and controls were markedly different in the percentage of scenes assigned to the three categories: aware, unaware, or intermediate (10.8 ± 4.5%, 55.8 ± 4.5%, and 33.3 ± 6.5% for patients; 60.4 ± 5.8%, 17.9 ± 2.5%, and 21.7 ± 3.9% for controls). Overall, the patients had robust knowledge (were aware) of only a few of the 24 manipulations (10.8% for patients vs. 60.4% for controls; $t[9] = 6.6$, $P < 0.001$, two-sample *t* test). One patient was not aware of any of the manipulations. Nevertheless, four of the patients occasionally identified scenes as manipulated and answered the queries correctly (i.e., they were designated as aware for these scenes). When we considered only scenes that were correctly identified as manipulated, controls were designated as aware of 87.9% of the manipulations and as having intermediate knowledge about 12.1% of the manipulations (patients, 31.0% and 69.0%, respectively).

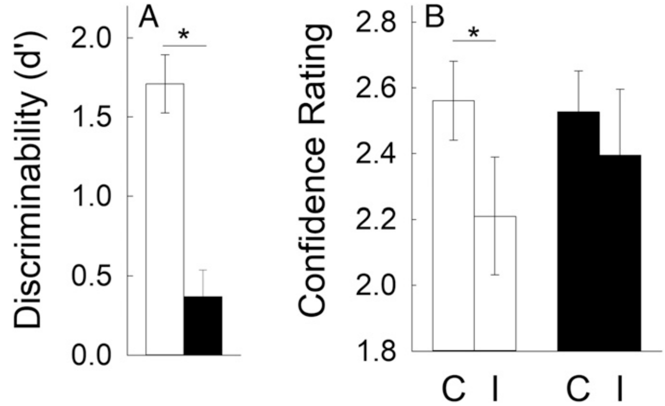


**Fig. 2.** Performance of controls ($n = 6$; white) and memory-impaired patients ($n = 5$; black). After viewing each scene in block 3, participants designated it as repeated or manipulated and then made a confidence judgment from 1 (maybe sure) to 3 (definitely sure). (*A*) The patients were impaired at discriminating between repeated and manipulated scenes. (*B*) Controls exhibited more confidence in their correct responses (C) than in their incorrect responses (I), but the patients did not. *$P < 0.05$. Error bars indicate SEM.

**Eye Movements in Response to Manipulated and Repeated Scenes.** We first asked whether eye movements differed in response to the manipulated and repeated scenes. Specifically, did participants direct more viewing toward the manipulated (critical) region of the manipulated scenes than toward the unchanged (critical) region of the repeated scenes? According to both eye movement measures, the controls exhibited this effect (Fig. 4; $t[5] > 8.0$, $P < 0.001$, paired *t* tests), but the patients did not ($t[4] < 0.7$, $P > 0.50$, paired *t* tests). In addition, for both eye movement measures, the controls viewed the critical region of manipulated scenes more than the patients did (Fig. 4; $t[9] > 4.0$, $P < 0.005$, two-sample *t* test).

Next, we examined the manipulation effect when participants either had or did not have robust knowledge of the manipulation (Fig. 5). Specifically, we compared repeated scenes to manipulated scenes when participants had robust knowledge of the manipulation (Y/Y/Y in Fig. 3) and when they had less knowledge, i.e., when they were either unaware of the manipulation (N/N/N in Fig. 3) or they had an intermediate level of knowledge (such as Y/N/N or N/Y/Y; Fig. 3). By both eye movement measures, controls and patients directed their gaze toward the manipulated region of the scene only when they had robust knowledge of the manipulation. In Fig. 5, compare Y/Y/Y scenes (black bars) to repeated scenes for both measures (for controls, $t[5] > 11.6$, $P < 0.001$; for patients, proportion of fixations: $t[3] = 5.0$, $P = 0.015$; proportion of time: $t[3] = 3.3$, $P = 0.045$, paired *t* tests). (One patient had no Y/Y/Y scenes and was not part of this calculation, resulting in a mean of 3.3 Y/Y/Y scenes per 24 scenes for the remaining patients; range = 1 to 6.) Neither controls nor patients exhibited the manipulation effect when they were unaware of the manipulation or had only partial knowledge about it. In Fig. 5, compare all non-Y/Y/Y scenes (gray bars) to repeated scenes for both eye movement measures (for controls, $t[5] < 1.9$, $P > 0.11$; for patients, $t[4] < 0.2$, $P > 0.80$, paired *t* tests).

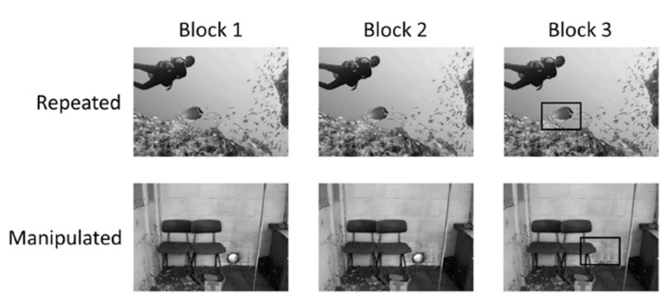


**Fig. 1.** Task design. In each of three test blocks, participants saw 24 color scenes (5 s per scene). Twelve scenes in block 1 were novel and were then repeated in blocks 2 and 3 (repeated scenes). Twelve other scenes in block 1 were novel, repeated in block 2, and then manipulated in a critical region in block 3 (manipulated scenes). No change occurred in the critical region of repeated scenes. The critical regions are identified by black squares (*Right*), but these squares did not appear during testing. The same testing sequence was repeated a second time with different scenes for a total of two sessions yielding 24 manipulated scenes and 24 repeated scenes.

In Fig. 5, the unaware and intermediate categories were combined because previous work had shown that partial knowledge about the manipulation is not sufficient to support a manipulation effect (14). The same was true in the present study (Fig. 6). For this analysis, data were combined for controls and patients ($n = 11$) to test as sensitively as possible whether a manipulation effect could be detected when participants had partial knowledge about the manipulation. Indeed, the manipulation effect (manipulated > repeated) occurred only when participants had robust knowledge (awareness) of the manipulation as defined by recognizing that a change had occurred, knowing what had changed, and knowing where the change occurred (Y/Y/Y scenes vs. repeated scenes; $t[9] > 8.5$, $P < 0.001$; one patient had no Y/Y/Y scenes). The separate means for Y/Y/Y scenes for controls in Fig. 6 *A* and *B* were 0.44 and 0.33, respectively; for patients, they were 0.52 and 0.32. The manipulation effect was not detected when participants had only partial knowledge about the manipulation (intermediate scenes as defined in Fig. 3 vs. repeated scenes; $t[10] < 0.3$, $P > 0.79$). The separate means for intermediate scenes for controls in Fig. 6 *A* and *B* were 0.18 and 0.16, respectively; for patients, they were 0.19 and 0.16.

We carried out one additional analysis of participants who had partial knowledge about the manipulation but did detect the manipulation itself, i.e., they detected the manipulation but failed to answer correctly one or both of the follow-up questions (Y/N/N, Y/N/Y, and Y/Y/N in Fig. 3). In these conditions, participants also did not exhibit the manipulation effect. They looked at the manipulated (critical) region of the manipulated scenes no more than they looked at the unchanged (critical) region of repeated scenes. The means for controls for the two measures were 0.17 and 0.13; for patients, they were 0.16 and 0.14 (compare with Figs. 5 and 6).

Note, in Fig. 6, that viewing associated with the critical region was somewhat lower for unaware scenes compared with repeated

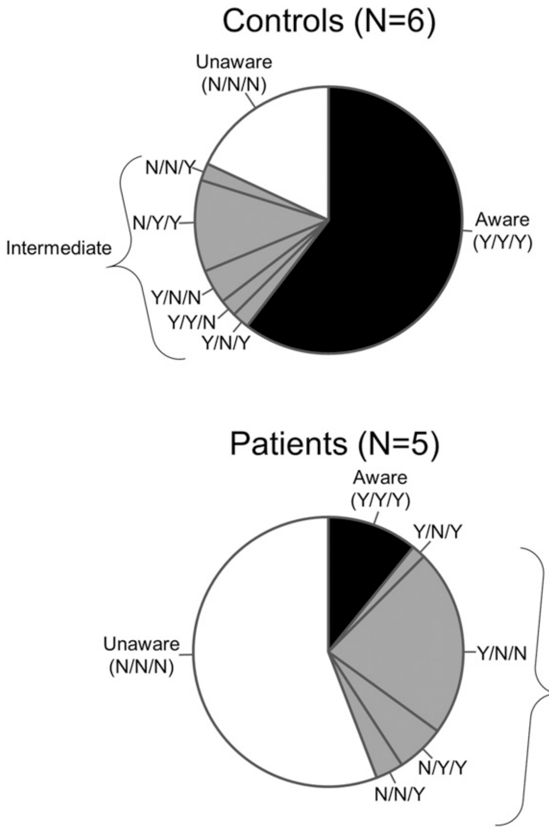


**Fig. 3.** For each of 24 manipulated scenes, participants were designated as having robust knowledge about the manipulation (aware), as unaware, or as having intermediate knowledge. For each manipulated scene, participants first indicated whether the scene was manipulated (Y or N). Then, after being told that a manipulation had occurred, participants were asked to describe what had changed (Y, correct; N, incorrect) and to indicate the location of the manipulated region (Y, correct; N, incorrect). For example, Y/Y/Y indicates scenes where participants answered all of the questions correctly. Y/N/Y indicates that participants reported a manipulation had occurred, then could not describe what had changed, but correctly indicated where in the scene a change had occurred. The charts show the percentage of manipulated scenes in each category. There were no N/Y/N scenes.

scenes. The separate means for unaware scenes for controls in Fig. 6 *A* and *B* were 0.12 and 0.13, respectively; for patients, they were were 0.15 and 0.18. This difference between unaware and repeated scenes is likely due to the fact that unaware scenes tended to be scenes from which an object had been removed (and where the critical region was therefore empty). By contrast, for scenes in the repeated condition, the critical region contained an object on half the trials (and was empty on half the trials). Viewing of a critical region tends to be lower when the region is empty than when the region contains an object.

## Discussion

We investigated how eye movements are affected by experience in patients with MTL lesions. In two separate sessions, participants viewed 24 different scenes twice in succession. Then they saw the scenes a third time, but for 12 of them a change (manipulation) was introduced. After viewing each of the 24 scenes, participants indicated whether the scene was repeated or manipulated. Later, participants were asked to identify what had changed (after being told a change had occurred) and to indicate where the change had occurred. The patients were impaired at discriminating between the 24 repeated and 24 manipulated scenes presented in the two sessions (Fig. 2). Patients and controls also differed markedly in how much knowledge they had about the manipulations (Fig. 3). Across all manipulated scenes, controls directed their viewing toward the region that had been changed (the manipulation effect), but the patients overall did not (Fig. 4). The manipulation effect occurred only when participants had robust knowledge about the manipulation, i.e., when they recognized that a change had occurred, identified what had changed, and also could indicate where the change had occurred (Figs. 5 and 6). Notably, MTL patients occasionally also had robust knowledge about the manipulations, and, for these few trials (mean = 3.3/24 scenes), they did exhibit the manipulation effect. Having partial knowledge about a manipulation was not sufficient to support the manipulation effect (Fig. 6; also see ref. 14).

It is worth emphasizing that the ability of MTL patients to be aware of a few manipulations (albeit many fewer than controls) is consistent with an extensive literature showing that memory impairment is seldom absolute after MTL lesions (15, 16); also see *Materials and Methods*, which documents the nonzero performance of the patients in the present study on three tests of anterograde amnesia.

The findings for patients show that conscious knowledge of what has been learned is an important factor determining the role of the MTL. If the nature of the task were the determining factor, one would have expected the manipulation effect in patients to be impaired consistently across all trials, not for the effect to be modulated by whether or not patients have conscious

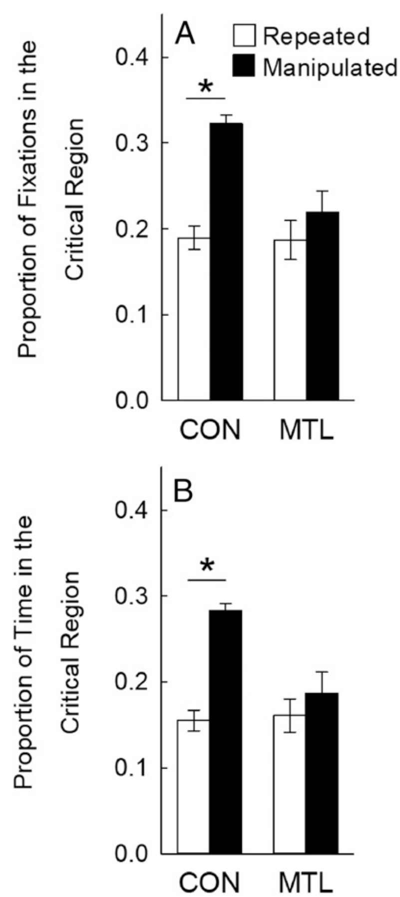


**Fig. 4.** Viewing of the manipulated (critical) region of manipulated scenes and the matched, unmanipulated (critical) region of repeated scenes. Controls (CON, $n = 6$) looked at the critical region of manipulated scenes more than they looked at the critical region of repeated scenes (i.e., the manipulation effect). Patients (MTL, $n = 5$) did not exhibit the manipulation effect. (*A*) The proportion of fixations in the critical region. (*B*) The proportion of time spent viewing the critical region. *$P < 0.05$. Error bars indicate SEM.

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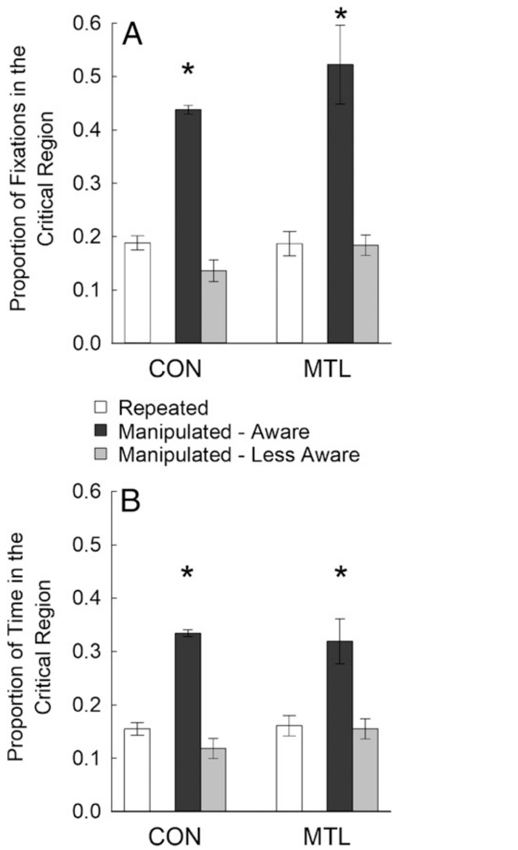


**Fig. 5.** Viewing of the manipulated (critical) region of manipulated scenes when participants had robust knowledge (were aware) of the manipulation. The less aware condition includes scenes where participants were designated as either unaware (N/N/N in Fig. 3) or as having intermediate knowledge (such as Y/N/N or N/Y/Y in Fig. 3). CON ($n$ = 6) and MTL ($n$ = 5) exhibited the manipulation effect (i.e., manipulated > repeated) only when they were aware of the manipulation (mean = 14.5/24 scenes for CON and 3.3/24 scenes for MTL). (*A*) The proportion of fixations in the critical region. (*B*) The proportion of time spent viewing the critical region. *$P < 0.05$ versus the repeated scenes. Error bars indicate SEM.

knowledge of the manipulations. However, in our study, the patients and controls exhibited the manipulation effect only when they had what we term robust knowledge about the manipulation. We could not detect a manipulation effect on trials when participants were unaware of the manipulation or had partial knowledge about it (Figs. 5 and 6).

Findings from an earlier report of a patient with hippocampal damage also show that the manipulation effect can be observed under some circumstances (17). In that study, the patient exhibited the manipulation effect when only ~2 s separated the first presentation of a scene and the presentation of a manipulated version (although not when many scenes needed to be remembered across minutes, as in the current study). We suggest that the manipulation effect was observed in the 2-s condition because memory of a single scene could be supported by working memory (i.e., memory of the scene could be actively held in mind).

The present findings, together with earlier work, show that the manipulation effect is a phenomenon of conscious memory. Notably, in three studies of the manipulation effect with young adults (and according to each of three eye movement measures), the manipulation effect was detected only when participants could identify the scene as manipulated and also describe what had changed (ref. 13, Experiment 1, $n = 20$; ref. 13, Experiment 2, $n = 20$; ref. 14, Experiment 2, $n = 51$). This finding was robust across the various methods used to study the manipulation effect. Specifically, the effect did not depend on whether participants expected or did not expect that memory would be tested (explicit methods vs. implicit methods), and it did not depend on whether or not participants knew that manipulations would occur. The present study extends these earlier reports by demonstrating the importance of awareness for the manipulation effect in the case of healthy older adults and MTL patients.

One study of the manipulation effect has seemed to contradict the link between aware memory and MTL-dependent memory (12). In that study, healthy young participants ($n = 12$) exhibited a manipulation effect despite being unaware of the manipulation (though the effect was found for only one of three eye movement measures). At the same time, a patient with lesions limited to the hippocampus (along with five other memory-impaired patients) did not exhibit the manipulation effect for that measure (see ref. 17 for documentation of this patient's

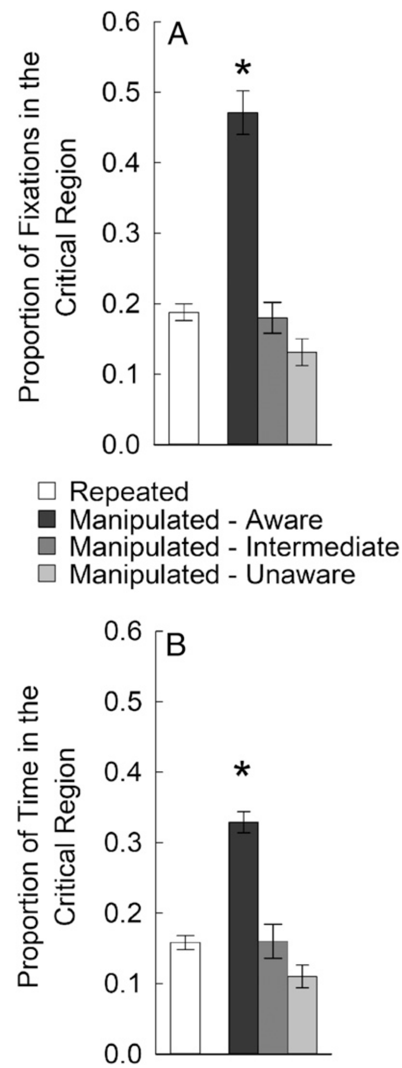


**Fig. 6.** Viewing of the manipulated (critical) region of manipulated scenes when participants (CON plus MTL, $n$ = 11) were designated either as having robust knowledge (awareness) of the manipulation (Y/Y/Y in Fig. 3), as unaware (N/N/N), or as having intermediate knowledge (such as Y/N/N or N/Y/Y; see Fig. 3). Participants exhibited the manipulation effect (i.e., manipulated > repeated) when they were aware of the manipulation but not when they were unaware or when they had partial knowledge about the manipulation. (*A*) The proportion of fixations in the critical region. (*B*) The proportion of time spent viewing the critical region. *$P < 0.05$ versus the repeated scenes. Error bars indicate SEM.

hippocampal lesions). The methods of this study were unique in that participants were invited, on each trial, to inspect the critical part of the image. If there are conditions under which a manipulation effect can occur in participants who are unaware of the manipulation (perhaps in the conditions unique to ref. 12), it would be useful to document the effect with a large number of participants and with multiple measures of eye movements.

Findings in support of the link between MTL function and conscious, declarative memory also come from other reports of experience-dependent eye movement effects. Thus, in the visual paired-comparison task, healthy participants spent more time viewing a novel scene than a repeated scene when the two scenes were presented simultaneously (18, 19), and this effect was correlated with measures of declarative memory. In addition, when novel and familiar scenes were presented one at a time, and participants made an old–new recognition judgment after viewing each scene, healthy participants explored the novel scenes more than the old (repeated) scenes (14, 20). This particular effect was observed only when participants were aware of which scenes were old and which were new. MTL patients were less aware than controls of the old/new status of the scenes, and they did not explore novel and repeated scenes differently.

Two other studies of experience-dependent eye movements support the link between MTL function and conscious memory in a different way (20, 21). In these cases, performance was independent of conscious memory and also was independent of the MTL. Specifically, when participants viewed a sequence of novel and repeated scenes and when there was no expectation of memory testing (and all viewing data were collected before memory was tested), healthy participants explored novel scenes more than repeated scenes regardless of whether they were aware or unaware of the old/new status of the scenes. MTL patients exhibited this same tendency to explore novel scenes more than repeated scenes. These examples provide evidence that eye movements can sometimes reflect nondeclarative memory.

Two neuroimaging studies of experience-dependent eye movements have been taken as exceptions to the link between MTL function and conscious, declarative memory (22, 23). In each study, hippocampal activity appeared to reflect past experience, as measured by eye movements, more reliably than did overt memory judgments. It will be important to determine whether these eye movement effects are hippocampus-independent or hippocampus-dependent. A recent study (24) of one of these phenomena (22) showed that the relevant eye movement effects strongly correlated with measures of conscious memory. We suggest that the available evidence supports the idea that performance on MTL-dependent tasks reflects conscious (aware) memory and that performance on MTL-independent tasks reflects unconscious memory.

## Materials and Methods

**Participants.** Five memory-impaired patients participated (mean age = 63.4 ± 8.2 y; mean education = 13.1 ± 0.8 y). Four have bilateral lesions thought to be limited to the hippocampus [cornu ammonis (CA) fields, dentate gyrus, and subicular complex], and one (G.P.) has larger MTL lesions (Table 1). For the five patients, the average score for delayed recall (30 min) of two short prose passages was 1.2 segments (25 segments per passage). The average score for delayed recall (10 min to 15 min) of a complex diagram was 5.8 (maximum score = 36). Paired-associate learning of 10 unrelated noun–noun pairs summed across each of three successive trials was 3.0 pairs (30 pairs total). On these same tests, 11 healthy controls scored 20.2 for the prose passages, 18.3 for the diagram, and 24.1 for paired-associate learning (25).

Patients D.A. and G.W. became amnesic in 2011 and 2001, respectively, following a drug overdose and associated respiratory failure. K.E. became amnesic in 2004 after an episode of ischemia associated with kidney failure and toxic shock syndrome. L.J. (the only female) became amnesic during a 6-mo period in 1988 with no known precipitating event. Her memory impairment has been stable since that time. G.P. has severe memory impairment resulting from viral encephalitis in 1987.

Estimates of MTL damage were based on quantitative analysis of magnetic resonance (MR) images from 19 age-matched, healthy males for K.E., G.W., and G.P., 11 age-matched, healthy females for patient L.J. (26), and 8 younger healthy males for D.A. Patients D.A., K.E., L.J., and G.W. have an average bilateral reduction in hippocampal volume of 35%, 49%, 46%, and 48%, respectively (all values at least 2.9 SDs from the control mean). On the basis of two patients (L.M. and W.H.) with similar bilateral volume loss in the hippocampus for whom detailed postmortem neurohistological information was obtained (27), the degree of volume loss in the four hippocampal patients may reflect nearly complete loss of hippocampal neurons. The volume of the parahippocampal gyrus (temporopolar, perirhinal, entorhinal, and parahippocampal cortices) is reduced by −5%, 11%, −17%, and 10%, respectively (all values within 2 SDs of the control mean). The negative values indicate volumes that were larger for a patient than for controls. These values are based on published guidelines for identifying the boundaries of the parahippocampal gyrus (28, 29). G.P. has an average bilateral reduction in hippocampal volume of 96%. The volume of the parahippocampal gyrus is reduced by 94%. G.P. also has a reduction of 24% (>3 SDs below control mean) in the left lateral temporal lobe and a reduction of 6% (<1 SD below control mean) in the right lateral temporal lobe. Eight coronal MR images from each patient, together with detailed descriptions of the lesions, can be found elsewhere (24).

Six healthy controls (one female) also participated (mean age = 62.0 ± 6.1 y; mean education = 13.7 ± 0.8 y). All procedures were approved by the Institutional Review Board at the VA San Diego Healthcare System, and participants gave written informed consent before participation.

**Apparatus.** Eye movements were recorded during testing by tracking pupillary position and corneal reflection. Eye movements were recorded at 1,000 Hz using an EyeLink 1000 Plus eye tracker (SR Research Ltd.) to identify fixations. Fixations were scored when >100 ms elapsed without a blink or a saccade. (When a fixation of <100 ms in duration occurred within 0.5° of another fixation, the two were counted as a single fixation if the total duration of the two exceeded 100 ms). A blink was scored when the image of the pupil was lost. A saccade was defined as an eye movement of at least 0.5° that occurred with a velocity exceeding 30°/s or an acceleration exceeding 8,000°/s$^2$. Head motion and position were maintained with a forehead and chin rest. The eye tracker was calibrated at the beginning of each test block by mapping the correspondence between 13 target locations and the direction of gaze when participants viewed each location. In addition, adjustments for head motion were carried out between trials when gaze direction drifted by >0.2°. Participants made their responses on a keyboard. A separate computer controlled scene presentation and recorded behavioral responses using EyeLink Experiment Builder software (version 1.10.1630). Stimuli were presented on an 18-in monitor (1,920 × 1,200 resolution) positioned 74 cm from the participant.

**Table 1. Characteristics of memory-impaired patients**

| | | | | WMS-R | | | | |
|---|---|---|---|---|---|---|---|---|
| Patient | Age, y | Education, y | WAIS-III IQ | Attention | Verbal | Visual | General | Delay |
| D.A. | 34 | 12 | 95 | 104 | 90 | 91 | 90 | 56 |
| K.E. | 75 | 13.5 | 108 | 114 | 64 | 84 | 72 | 55 |
| L.J. | 79 | 12 | 101 | 105 | 83 | 60 | 69 | <50 |
| G.W. | 58 | 12 | 108 | 105 | 67 | 86 | 70 | <50 |
| G.P. | 71 | 16 | 98 | 102 | 79 | 62 | 66 | 50 |

WAIS-III is the Wechsler Adult Intelligence Scale-III, and WMS-R is the Wechsler Memory Scale—Revised. The WMS-R does not provide numerical scores for individuals who score <50. The IQ score for D.A. is from the WAIS-IV.

**Experimental Design and Statistical Analysis.**

***Procedure.*** A total of 48 color photographs of indoor or outdoor scenes were used. In each of three blocks (Fig. 1), 24 scenes were presented for 5 s each (visual angle for each scene = 30.7° × 22.6°). After each scene presentation, a red crosshair appeared for 3 s on a gray background. Two types of scenes were presented. Twelve scenes were novel in block 1 and were then repeated in blocks 2 and 3 (repeated scenes). Twelve other scenes were novel in block 1, repeated in block 2, and then manipulated in block 3 (manipulated scenes). A 2- to 5-min interval separated the blocks. Half of the manipulations consisted of adding an object to a previously studied scene, and half consisted of removing an object from a previously studied scene. The manipulation occurred in one region of either a $4 \times 4$ grid of 16 equal-sized regions (for 42% of scenes) or a $3 \times 3$ grid of 9 equal-sized regions (for 58% of scenes). The type of grid used depended on the size and location of the manipulated object. The procedure of the current study differed from the procedure of our earlier studies (13, 14) in that we presented manipulated scenes and repeated scenes in blocks 2 and 3, not manipulated, repeated, and novel scenes.

All scenes were available in an original and a manipulated version. For each scene, a critical region was identified where the manipulation would occur whenever the scene was assigned to the manipulation condition. The scenes were counterbalanced across participants such that the original and the altered version of each scene served equally often in each of the three test blocks and in the repeated and manipulated conditions. Participants were tested on two separate occasions, each time using 24 different scenes (12 repeated scenes and 12 manipulated scenes) (mean interval between the two testing sessions was 100 d).

Before testing, participants were instructed to pay attention to the scenes so they might be able to recognize them later. No response was required during blocks 1 and 2. Before block 3, participants were instructed that they would next see scenes that were either repeated or altered. After each scene was presented, participants indicated the scene's status and their confidence by pressing a key on a six-point scale ("Definitely Identical," "Probably Identical," "Maybe Identical," "Maybe Changed," "Probably Changed," and "Definitely Changed"). After block 3 was completed, the 12 manipulated scenes were presented again, one at a time. Participants were told that a manipulation had been introduced in each scene and were asked to describe the manipulation. They were then asked to use a computer mouse to place a cursor on the region that had changed.

***Designation of awareness.*** For each manipulated scene in block 3, participants were assigned to one of three categories according to how much knowledge they had about the manipulation. Assignment was based on how participants responded to the three queries described in the previous paragraph: (*i*) Was the scene manipulated? (*ii*) What was changed? (*iii*) Where did the manipulation occur? If all responses were correct, participants were designated as having what we term robust knowledge or awareness (Y/Y/Y; see Fig. 3). They were designated as unaware if none of the responses were correct (N/N/N; see Fig. 3). They were designated as having intermediate (or partial) knowledge if only one or two responses were correct (such as Y/N/N or N/Y/Y; see Fig. 3).

***Data analysis.*** The behavioral data and the eye movement data were taken from block 3 of each session and combined (total = 24 repeated scenes and 24 manipulated scenes). The ability to discriminate between repeated and manipulated scenes in block 3 (d′) was calculated from the responses on the six-point scale, which ranged from "Definitely Identical" to "Definitely Changed." A hit was a correct response for a scene that was changed regardless of confidence rating. A false alarm was an incorrect response for a scene that was identical. The confidence associated with the judgment of a scene's status (identical or changed) was also calculated from responses on the six-point scale. A response of "Maybe identical" or "Maybe changed" was assigned a score of 1. A response of "Probably Identical" or "Probably Changed" was assigned a score of 2. A response of "Definitely Identical" or "Definitely Changed" was assigned a score of 3. Confidence ratings were calculated separately for correct and incorrect responses.

Two measures were used for block 3 to assess the extent to which participants viewed the critical (manipulated) region of the manipulated scenes and the extent to which they viewed the critical (unmanipulated) region of repeated scenes: (*i*) proportion of fixations in the critical region—the number of fixations in the manipulated region divided by the total number of fixations during 5 s; and (*ii*) proportion of viewing time in the critical region—the amount of time spent viewing the manipulated region divided by total viewing time (5 s). The measure of viewing time is similar to but not identical to the measure of fixations, because viewing time will be affected by the length of the fixations.

The manipulation effect was assessed by comparing viewing of manipulated scenes to viewing of repeated scenes. Comparisons within groups were done with paired *t* tests. The size of the two groups (controls, $n = 6$; MTL patients, $n = 5$) was similar so that the power to detect eye movement effects would be similar in the two groups. Comparisons between groups were done with two-sample *t* tests. The *t* tests were carried out using Systat software (version 13.00.05).

**ACKNOWLEDGMENTS.** We thank Isabel Asp, Jennifer Frascino, Ryan Ward, and Julia Gulliver for assistance. This work was supported by the Medical Research Service of the Department of Veterans Affairs (Program 51K6CX001644), Award CX000359, and National Institute of Mental Health Grant 24600.

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