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Intact Implicit Memory for Newly Formed Verbal Associations in Amnesic Patients Following Single Study Trials

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This study examines the ability of amnesic patients to recover newly formed associations implicitly after a single study trial. Fifteen amnesic patients with various etiologies studied pairs by forming a sentence containing both words. At test, all participants saw 40 intact pairs, 40 rearranged pairs, and 40 new words. All pairs appeared side by side both at study and at test. For the implicit lexical-decision task, 40 nonwords were intermixed with the other pairs, and participants indicated whether both items were words. For the explicit speeded-recognition test, participants were asked to indicate whether both words had appeared at study. Despite being severely impaired on the explicit test, amnesic patients performed like healthy controls on the implicit test, with faster and more accurate responses to intact pairs than to recombined pairs. Contrary to existing theories, the results suggest that amnesic patients can form and retain new associations.

Global amnesia is characterized by an inability to remember new episodes and facts accompanied by intact performance in other cognitive domains (Squire, 1992a, 1992b). The amnesic syndrome occurs as a consequence of bilateral damage to structures in the medial temporal lobe, diencephalon, or basal forebrain structures. The precise characterization of the functional deficit that underlies amnesia is the subject of ongoing debate and is the focus of this article.

According to one suggestion, amnesia is best characterized as a deficit in conscious recollection, as indexed by explicit tests of memory (for reviews, see Cohen & Eichenbaum, 1993; Moscovitch, 1982; Squire, 1992a, 1992b). According to this explicit-memory-deficit hypothesis, amnesic patients are impaired on tests that require conscious recollection, such as recall and recognition. Performance is preserved, however, on implicit tests, in which a nonconscious influence of past experience is found on current behavior, as indexed by measures such as repetition priming, which is the difference in test performance between items (e.g., words, objects) that were presented in an earlier study phase and baseline items that were not (Cermak, Talbot, Chandler, & Wolbarst, 1985; Diamond & Rozin, 1984; Graf, Squire, & Mandler, 1984; Rozin, 1976).

A different characterization of amnesia suggests that not all forms of implicit memory are spared in amnesia (Squire, 1992b). Thus, whereas implicit memory is preserved for item-specific (nonrelational) information, it is impaired for association-specific (relational) information. According to this relational-deficit hypothesis, amnesic patients are impaired in their ability to "relate or bind together into a compositional representation any set of perceptually distinct objects or events" (Cohen, Poldrack, & Eichenbaum, 1997, p. 135). Support for the hypothesis is based on converging evidence from neuroimaging (e.g., Cohen et al., 1994), functional neuroanatomy (for a comprehensive review, see Eichenbaum, Otto, & Cohen, 1992), and neurophysiology (e.g., Young, Fox, & Eichenbaum, 1994). The relational-deficit hypothesis predicts, therefore, that memory for relational information should not be observed in amnesia, even when testing is implicit.

The question of whether amnesic patients are able to display implicit memory for new associations is important not only for determining the functional deficit underlying amnesia but also for understanding the nature of the particularly pronounced deficit found in remembering new associations (e.g., Shimamura & Squire, 1984). According to the relational-deficit hypothesis, the impairment results from an inability to form new associations in memory and, as such, reflects an encoding deficit that affects subsequent explicit as well as implicit tests. Alternatively, the explicit-memory-deficit hypothesis states that amnesic patients are able to form new associations but are unable to retrieve them consciously. According to this hypothesis, new associations cannot be retrieved on explicit tests, but they can be recovered on implicit tests.

One way of distinguishing between the two hypotheses is to use a verbal paired-associate learning paradigm and test memory implicitly. To investigate implicit memory for

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newly formed associations, one can examine whether responses to word pairs are faster or more accurate when these pairs are presented in the *intact condition*, using the same combinations as at study (e.g., study: *skirt–couch, purse–sauce*; test: *skirt–couch, purse–sauce*), than in the *recombined condition*, where study pairs are rearranged (e.g., study: *skirt–sauce, purse–couch*; test: *skirt–couch, purse–sauce*). Because all the words are presented for study, an advantage for the intact over the recombined pairs, if found, can only be explained in terms of implicit memory for association-specific information. Memory for item-specific information can also be measured by comparing performance in the recombined condition against a new condition, consisting of two unstudied words.

Three key criteria must be met for a valid demonstration of intact implicit memory in amnesia. First, an association-specific effect must be observed on an implicit test in amnesic patients. Second, these same patients must show impaired performance on an explicit test, in which identical retrieval cues are provided to those presented in the implicit test (e.g., Schacter, Bowers, & Booker, 1989). If different retrieval cues are used in the explicit test, it leaves open the possibility that had identical retrieval cues been provided, association-specific memories would have been observed, even on the explicit test. Such a finding would suggest that the patients tested were not profoundly amnesic and had residual explicit memory that contributed to performance on the implicit test. Such a finding would undermine the interpretation that memory for the newly formed associations was truly implicit.

Third, patients should provide different responses when studying the word pairs than when retrieving them. This criterion must be met to distinguish association-specific effects from the domain-specific gradual strengthening of response associations that has already been demonstrated for amnesic patients in classical conditioning (e.g., Clark & Squire, 1998; Gabrieli et al., 1995; Weiskrantz & Warrington, 1979) and in skill-learning tasks (e.g., Cohen & Squire, 1980; Heindel, Salmon, Shults, Wallicke, & Butters, 1989; Milner, 1966; Milner, Corkin, & Teuber, 1968; but see Poldrack, Selco, Field, & Cohen, 1999).

Strengthening of response associations, rather than association-specific information per se, can arguably occur whenever participants make the identical responses to stimuli at study and test (e.g., reading the words aloud). If associative memory is only displayed under such conditions, it is not clear that participants did not, for example, simply acquire knowledge of the motor programs of coarticulation between the words. Conceivably, such knowledge could drive the entire association-specific effect. Therefore, for a skill-learning account to be dismissed, different responses must be made to stimuli at study than at test (for similar arguments, see Cohen et al., 1997; Monti, Gabrieli, Wilson, Beckett, & Reminger, 1997).

Several researchers (Cermak, Bleich, & Blackford, 1988; Schacter & Graf, 1986; Shimamura & Squire, 1989) have used a stem completion task (e.g., *skirt–cou__*) and found no intact association-specific effects for patients with profound amnesia. Similarly, association-specific effects were not found when words were sequentially presented at threshold durations, and patients were required to identify them (Paller & Mayes, 1994). Attempts at finding association-specific effects in amnesic patients using associations between words and the voice in which they were spoken also did not yield significant effects (Kinoshita & Wayland, 1993; Schacter & Church, 1995; Schacter, Church, & Bolton, 1995). Although these findings confirm the relational-deficit hypothesis, they can also be interpreted as suggesting that the association-specific effect that was observed in normal people stemmed from contamination by explicit memory. This would corroborate the suggestion that implicit associative effects depend on explicit retrieval (Bowers & Schacter, 1993; Reingold & Goshen-Gottstein, 1996) in nonamnesic people as well (Graf & Schacter, 1985).

By contrast, Moscovitch, Winocur, and McLachlan (1986), who used reading speed as the measure of memory, did succeed in finding an intact association-specific effect. Their study examined a mixed group of focal amnesic and Alzheimer's disease patients and found that reading of intact pairs was faster than reading of recombined pairs. The interpretation of these findings, however, is not unequivocal because the association-specific effect was not reported for the amnesic patients alone. Of more importance, because participants made the same overt responses at study and test (i.e., reading the words aloud), it is not clear that participants did not learn the patterns of coarticulation between the word pairs and thus exhibited skill learning. A skill-learning account was, in fact, implicated when, in an attempt to replicate their findings, Musen and Squire (1993) were only able to show an association-specific effect when each pair was studied 10 times. Still, it should be noted that the methods used by Musen and Squire were not identical to those reported by Moscovitch et al.

Recently, Gabrieli, Keane, Zarella, and Poldrack (1997) found intact association-specific priming in a perceptual-identification task, but they, too, required patients to make the identical overt responses to test stimuli as they had to study stimuli (reading the words aloud). That the effects were only reported when patients studied each word pair twice further implicates a gradual skill-learning mechanism.

Of more importance, a different set of retrieval cues was provided in the explicit test than in the implicit test. In the implicit test, perceptually degraded word pairs were presented in one of three independent conditions (intact, recombined, or control). In the recognition test, conditions were dependent, with patients required to choose the one word out of three (corresponding to the three conditions) that had appeared in the study phase together with the target word. This procedure attenuated possible explicit associative effects because an erroneous response with the recombined choice elevated the proportion of recombined responses and, at the same time, reduced the proportion of intact responses. The power to detect an explicit associative effect was further reduced because each patient saw 20 test trials, as compared with 60 trials in the implicit test. Finally, a two-tailed test was applied rather than the more sensitive one-tailed test, which was appropriate. In summary, the procedure adopted by Gabrieli et al. (1997) was more sensitive in detecting an association-specific effect (if such an effect exists) for the implicit than for the explicit test. Therefore, the question remains open whether densely amnesic patients can form new associations.

We first addressed this question by asking normal participants to study a list of unrelated word pairs by forming sentences with them (Goshen-Gottstein & Moscovitch, 1995c). For the implicit test, we showed them intact, recombined, and new pairs intermixed with pairs consisting of pronounceable nonwords. The words constituting the pairs appeared simultaneously, side by side, during both encoding and retrieval. Participants were asked to indicate whether both items were words, a response that was different from the one they used at study so that associative effects, if found, could not be attributed to a skill-learning mechanism. Using this lexical-decision task, we found association-specific effects.

The identical retrieval cues were used in the explicit and implicit version of the test, as demanded by our criteria. Participants had to indicate whether both words that appeared on the screen were old without regard to whether they had appeared in the same combination as before. This eliminated possible confounds between the lexical-decision task and the explicit recognition task by ensuring that for both tasks, participants would always make the same decision and produce the same response for intact pairs as they did for recombined pairs. Thus, the speeded-recognition task simulated the explicit processing that participants would perform if they depend on conscious recollection to support their performance on the lexical-decision task.

Several dissociations were found between the explicit and the implicit tests (Goshen-Gottstein & Moscovitch, 1995b, 1995c), suggesting that the implicit test was truly tapping different memories from the explicit test. Having established a procedure for obtaining associative priming effects in neurologically intact participants, we examined, in this article, performance of amnesic patients.

Method

Participants

Fifteen amnesic people (4 women, 11 men) and 12 controls (5 women, 7 men) participated in the study. The mean age of the amnesic people was 50.7 years, and the mean age of the controls was 55.5, $t(25) = 1.54$, $p > .1$. Mean education of both groups was 13.6 years. All but 2 of the amnesic patients and 1 of the controls were right-handed.

Three of the amnesic people had herpes encephalitis, 2 had closed-head injuries, 2 had communicating artery aneurysms (one anterior and the other anterior and posterior), 2 had anoxia, 2 had cerebral vascular accidents, and, of the remainder, 1 had Korsakoff's syndrome, 1 had an astrocytoma, 1 had an arteriovenous malformation that led to excision of the right temporal lobe, and 1 had bilateral medial temporal lobe lesions of unknown origin following an operation for gastric stapling.

All patients had either diffuse or focal damage confirmed by computerized tomography scans or electroencephalographs that included bilateral medial temporal lobe lesions in 8 people, unilateral medial temporal lobe lesions in 2 (although it is suspected that in at least 1 of these cases there was some involvement of the other temporal lobe as well), basal forebrain lesions following left anterior communicating artery aneurysm in 2 patients (1 of whom was left-handed and the other of whom also had a left posterior communicating artery aneurysm), and bilateral diencephalic lesions in 3 patients (1 of whom was left-handed).

Table 1 shows the mean scores of the amnesic group on tests of intelligence and memory. We attempted to administer the Wechsler Adult Intelligence Scale—Revised (WAIS–R; Wechsler, 1981), the Wechsler Memory Scale (Wechsler & Stone, 1945), the National Adult Reading Test (NART; Nelson, 1982), and Warrington's (1984) Recognition Memory Test (RMT) to all of the amnesic people, but in some cases, we could not complete the testing before the person left the study. Although the etiology and locus of lesion was variable across the people in the amnesic group, all amnesic patients for whom we had data had a full scale IQ, a verbal IQ, and a performance IQ at least in the normal to low normal range, as determined by the WAIS–R and the NART. For all but 3 of the amnesic people, the verbal memory index was 1 *SD* below the verbal IQ, and for all but 2 of them, the delayed index was more than 2 *SD*s lower. For all but 3 of the patients, performance on the RMT fell below the 5th percentile. Even for those patients who performed better than most on the memory tests, amnesia was sufficiently severe that none could lead a fully independent existence, and many required extensive supervision.

Table 1 also provides data on some other neuropsychological tests. There was mild impairment on verbal fluency in 5 people, semantic fluency in 4, naming in 1, and poor performance on the Wisconsin Card Sorting Test (Heaton, 1981) in 5. This is what would be expected in a heterogeneous group with lesions that implicate the frontal lobes, basal forebrain, and diencephalon in some people.

All amnesic people were tested on the implicit version of the associative memory test that preceded the explicit version in all cases. Only 11 of them participated in the explicit version. Three of the people left the study before testing was completed and 1 died. All 12 controls participated in both versions of the test.

Table 1
Mean Scores on a Battery of Neuropsychological Tests

Neuropsychological test	*M*
Wechsler Adult Intelligence Scale—Revised ($n = 15$)	
Full scale IQ	96.0
Verbal IQ	103.0
Performance IQ	89.8
Wechsler Memory Scale—Revised ($n = 15$)	
Verbal Index	75.5
General Memory	73.4
Delayed Index	62.0
Recognition Memory Test ($n = 14$)	
Words	32.4
Faces	33.7
National Adult Reading Test[a] ($n = 11$)	109.5
Fluency[b] ($n = 14$)	
Verbal/Phonemic	33.4
Semantic	14.8
Boston Naming Test ($n = 12$)	50.8
Wisconsin Card Sorting Test ($n = 14$)	
Categories	4.2
Perseverative errors	17.5

[a] American version. [b] 1-min fluency tests.

Design and Materials

Pair type (intact, recombined, new) and test type (implicit, explicit) were manipulated within-subject. Participant group (amnesic, control) was a between-subjects variable.

The critical test items were 120 word pairs, with Francis and Kucera (1982) frequencies ranging between 10 and 397 occurrences per million (o/m; $M = 65$, $SD = 89$). These pairs were organized into 60 double-pair arrays. For the sake of brevity, we refer to the pairs that made up the double-pair arrays as A–B and C–D pairs (e.g., *skirt–couch, purse–sauce*) and label the A and C items as context words and the B and D items as target words. The intact and recombined conditions were created by selecting the pairs within an array according to one of two possible combinations of context and target words.

Test conditions were established by varying study pairs within-subject and keeping test pairs uniform across conditions and across participants (e.g., for a particular array, uniform test presentation may have been A–B, C–D). If pairs were presented in their intact form during study (i.e., A–B, C–D), then the uniform presentation at test constituted the intact condition for that participant. If pairs were presented in their recombined form during study (i.e., A–D, C–B), then the uniform presentation at test constituted the recombined condition and provided a baseline measurement for the association-specific effects. Finally, if the pairs forming the array were not presented at study, then the uniform presentation at test constituted the new condition and provided a baseline measurement for the item-specific effects.

Three constraints were observed in the construction of the double-pair arrays. First, within each array, the word frequency of the target words was equated. The B items had a mean Francis and Kucera (1982) word frequency of 57.3 o/m ($SD = 73.4$), compared with 57.56 o/m ($SD = 82.1$) for the D items (Pearson's $R^2 = .98$, $p < .001$). A paired t test did not find this difference to be significant, $t(59) < 1$. No constraints were imposed on the context words because they were identical for the intact and recombined pairs.

The second constraint was that within an array, all members were randomly related. Although some obscure relation can always be created for any two words, no obvious semantic relation existed between any of the pairs. The third constraint was that all target words were monosyllabic five-letter words. The context words were also five-letter words and, within an array, were always equated in syllable length. Across arrays, however, some of the context words were monosyllabic and some were bisyllabic.

For counterbalancing purposes, the 60 double-pair arrays were divided into three blocks of 20 arrays (i.e., 40 pairs). Three study lists were then constructed by assigning two of the three blocks to each of the study lists, for a total of 80 pairs per study list. One block was assigned in its intact form, and one block was assigned in its recombined form. This ensured that each participant would be tested in the three pair-type conditions an equal number of times (40 pairs). Assignment of the blocks to the lists was made in accordance to a Latin-square design so that across participants, each target word would appear in the three pair-type conditions an equal number of times.

In addition to the 80 pairs presented during study, which would later constitute the intact and recombined conditions, 20 extra pairs, identical for each of the study lists, were added to the study lists (for a total of 100 study pairs). The 40 five-letter words that formed these pairs were to be included in the test list in foil trials that contained studied words as well as nonwords (in the implicit-test condition) or new words (in the explicit-test condition). Inclusion of studied words in the foil trials of the implicit test would ensure that study status of the context word was not confounded with the decision on lexicality.

In the implicit-test condition, the test list contained 120 word pairs intermixed with 40 foil trials. The foil trials consisted of 40 trials that contained a studied word (from the 20 extra pairs) and a nonword, with the nonword serving as context on half the trials and as target on the other half. All nonwords were derived from legal English words by changing one letter and substituting it with an equal-frequency letter bigram. The parent English words were five-letter words with one or two syllables.

For the explicit-test condition, new words (that had not been presented during study) replaced the nonwords in the 40 pairs that contained a nonword, with the new word serving as context on half the trials and as target on the other half. This way, half the test trials were old trials (40 intact, 40 recombined) and half the test trials were new trials (40 new–new, 20 new–old, 20 old–new). In all other respects, the explicit-test condition was identical to the implicit-test condition.

Procedure

Individually tested amnesic and control participants were first administered the implicit-test condition and then, on a later date, the explicit-test condition. On average, 22 days lapsed between the two test sessions. Participants were allocated to the same counterbalancing group on the two test sessions.

Participants were told that they would be shown word pairs. They were asked to create a sentence that contained the two words, was meaningful, and retained the order of the words as they appeared on the screen. Following 10 practice trials (in which feedback was given), the 100 study pairs were presented on the screen of a MacIntosh Plus computer in random order for each participant.

During all stages of the experiment, the context words were presented to the left of the target words. To equate the duration of perceptual exposure to each stimulus, each pair was presented for 5 s, after which it disappeared. Participants were required to generate a sentence even if the pair was no longer visible. After encoding the study pairs, participants activated the next trial by pressing the space bar. Typically, the time delay between the beginning of the study phase and the beginning of the test phase was 35 min.

After presentation of the study list, participants in the implicit-test session were told that they would perform a distractor task (in truth, the implicit lexical-decision task). They were asked to press, as quickly and with as few errors as possible, the "M" key with the right hand index finger if both letter strings were legal English words and the "Z" key with the left hand index finger if one or both letter strings were not English words (instructions were reversed for left-handed participants, for this and for subsequent procedures).

In the explicit-test session, participants were told that their memory for studied items would be tested. If both members of the pairs had previously been presented, either together or in separate pairs, participants were required to press "M" as quickly and with as few errors as possible. If one or both the words had not been presented during study, participants were required to press "Z." For both the implicit and explicit conditions, 10 practice trials were first given, and the test list was then presented in a different random order for each participant.

Results

Means were calculated from the reaction time (RT) distributions of correct responses, whose skewness was reduced by eliminating values that were more than 2 *SD*s above the mean for that condition, for each participant in each of the three within-subject conditions. These means were then averaged across participants in the implicit-test session and for participants in the explicit-test session. Table 2 presents the means, for both patients and controls, along with the mean percent errors.

Association-specific repetition effects were calculated by subtracting performance in the intact condition from the recombined condition. Likewise, item-specific repetition effects were calculated by subtracting performance in the recombined condition from performance in the new condition.

Examination of the RT data revealed that for the lexical-decision task, not only controls but also amnesic patients showed an item-specific effect and, more importantly, an association-specific effect. The association specific-effect that was found for the amnesic patients was very large (109 ms), indeed surprisingly larger than for the controls (23 ms). With regard to the accuracy data, only negligible effects were found, with both groups making fewer errors to recombined than to intact pairs, as well as fewer errors to recombined pairs than to new pairs.

The lexical-decision data were submitted to a two-way analysis of variance (ANOVA), with pair type (intact, recombined, new) as a within-subject variable and group (amnesic, control) as a between-subjects variable. All hypotheses were tested as two-tailed. The RT main effect of group was significant, $F(1, 25) = 14.54$, $p < .001$, with faster responses of controls (M = 756 ms, SE = 33) than of amnesic patients (M = 1,318 ms, SE = 129). Of more importance, the main effect of pair type was significant, $F(2, 50) = 36.24$, $p < .00001$, with the fastest responses for the intact pairs (M = 992 ms, SE = 81), slower responses for recombined pairs (M = 1,062 ms, SE = 97), and the slowest responses for new pairs (M = 1,151 ms, SE = 94). The Group × Pair Type interaction also achieved significance, $F(2, 50) = 4.93$, $p < .05$.

Post hoc analysis (Levin, Serlin, & Seaman, 1994) revealed a significant 89-ms item-specific effect, $F(1, 25) = 50.06$. The Pair Type (recombined, new) × Group interaction was not significant, $F(1, 25) < 1$.

Of most importance to our concerns, post hoc analysis revealed that the 70-ms association-specific effect was also significant, $F(1, 25) = 8.91$, $p < .01$. Indeed, the association-specific effect was significant for both amnesic patients, $F(1, 14) = 7.98$, $p < .05$, and for controls, $F(1, 11) = 6.09$, $p < .05$. Moreover, the interaction between pair type (intact, recombined) and group was marginally significant, $F(1, 25) = 3.83$, $p = .06$, characterizing the larger association-specific effect for the amnesic patients than for the controls. In the Discussion, we discuss this unexpected finding. For now, we conclude that the latency data provide compelling evidence that amnesic patients were able to store and retain association-specific information.

In the analysis of the accuracy data, only the main effect of pair type (intact, recombined, new) was significant, $F(2, 50) = 8.46$, $p < .001$. Post hoc analysis revealed that the main effect was the result of the less accurate processing of new pairs than of recombined pairs, $F(1, 25) = 13.26$, $p < .01$. That the processing of intact and recombined pairs was not significantly different, $F(1, 25) < 1$, suggests that the association-specific effect that was observed in the latency data was not the result of a possible speed–accuracy tradeoff.

After demonstrating that the amnesic patients can store and retain association-specific information when tested implicitly, we examined explicit memory performance of these patients and of their controls. Because responses to recombined and new pairs were confounded with the hand (dominant, nondominant) and with decisions (old, new), memory for item-specific information could not be indexed in the explicit-test condition. Therefore, in the explicit-test condition, only performance in the intact and the recombined conditions was analyzed.

Examination of performance on the speeded-recognition task revealed that RTs to intact pairs were 500 ms faster than to recombined pairs for control participants. For amnesic patients, however, equivalent latencies were found for intact and recombined pairs. Equivalent performance in these two conditions was also observed for the accuracy data of the amnesic patients, which contrasted with the 31% association-specific effect observed in the normal controls.

First, we analyzed the accuracy data. In an ANOVA, with pair type (intact, recombined) as a within-subject variable

Table 2
Lexical-Decision and Speeded-Recognition Mean Reaction Times (in Milliseconds) and Mean Percent Error by Pair Type and Group

Pair type	Patients *M*	Patients % error	Controls *M*	Controls % error
Lexical decision				
Intact	1,213	.052	715	.042
Recombined	1,322	.048	738	.012
New	1,420	.082	815	.033
Association effect[a]	109	−.004	23	−.030
Item effect[a]	98	.034	77	.021
Speeded recognition				
Intact	1,684	.469	1,352	.157
Recombined	1,683	.461	1,860	.468
New	1,895	.595[b]	1,801	.770[b]
Association effect[a]	−1	−.008	508	.311
Item effect[c]				

[a] Association-specific effects (recombined − intact) and item-specific effects (new − recombined) are indexed by positive values. [b] Although the errors in the intact and recombined conditions constitute misses, the errors for the new pairs constitute false alarms. [c] An item-specific effect could not be calculated in the speeded-recognition task because responses to recombined and new pairs were confounded with response hand (dominant, nondominant) and with the decision (old, new).

and group (amnesic, control) as a between-subjects variable, amnesic patients made significantly more errors (M = 0.47, SE = 5.6) than did controls (M = 0.31, SE = 4.8), $F(1, 20) = 4.23$, $p = .053$. Furthermore, fewer errors were made to intact pairs (M = 0.31, SE = 4.5) than to recombined pairs (M = 0.46, SE = 4.9), $F(1, 20) = 16.34$, $p < .001$. The meaning of this association-specific effect, however, could only be interpreted in light of the significant two-way interaction between group and pair type, $F(1, 20) = 18.05$, $p < .001$. The source of this interaction was the large association-specific effect that was found for controls, $F(1, 10) = 28.40$, $p < .001$, coupled with a null effect (in fact, an effect in the opposite direction) for the amnesic patients, $F(1, 10) < 1$. Thus, although control participants displayed better memory to intact, as compared with recombined, pairs, no such advantage was found in the performance of the amnesic patients.

Finally, we analyzed the latency data even though the error rate was high and amnesic patients were performing at chance. Responses for controls (M = 1,606 ms, SE = 167) were not significantly faster than for amnesic patients (M = 1,683 ms, SE = 1,123), $F(1, 20) < 1$. Furthermore, responses to intact pairs (M = 1,518 ms, SE = 90) were faster than to recombined pairs (M = 1,771 ms, SE = 129), $F(1, 20) = 8.36$, $p < .001$. Of most importance, the two-way interaction between group and pair type was significant, $F(1, 20) = 8.42$, $p < .001$. The source of this interaction was the large association-specific effect that was found for controls, $F(1, 10) = 15.90$, $p < .01$, which, once again, was coupled with an effect in the opposite direction for the amnesic patients, $F(1, 10) < 1$. Thus, in contrast to the implicit-test condition, where the amnesic patients revealed association-specific effects, in the explicit-test condition, these patients did not reveal association-specific effects in either measures of accuracy or of latency.

The association-specific effect that the amnesic patients displayed on the implicit test would be uninformative if it were driven by patients in which residual explicit memory capabilities remained intact (e.g., Schacter & Graf, 1986). Therefore, we reanalyzed performance on the lexical-decision task, excluding 5 patients for which responses in the intact condition of the speeded-recognition test were more accurate than in the recombined condition of that test. Even though for any particular patient, this pattern may be the result of chance, this strict criterion for exclusion from the analysis was applied, to avoid possible misinterpretations of the results.

Critically, the remaining patients showed facilitated lexical-decision performance in the intact condition (M = 1,272 ms, SE = 166) relative to the recombined condition (M = 1,383 ms, SE = 207), $F(1, 9) = 3.74$, $p = .04$, one-tailed. A significant difference was not found in the error rates of these conditions ($F < 1$). Thus, even under a most conservative analysis of the data, including only patients that showed no residual explicit memory capabilities, an association-specific repetition effect was still found.

Discussion

In this study, amnesic patients demonstrated an ability to form new associations in a single trial and to retain the association-specific information over durations lasting more than 30 min. The effects were obtained using a simultaneous lexical-decision task, with the patients indicating whether both of two letter strings were legal English words. Facilitated performance was found for the intact-pair condition as compared with the recombined-pair condition. Thus, our study demonstrates intact association-specific priming in amnesia while satisfying all three key criteria (see the introduction).

Although the same retrieval cues were provided for the explicit and implicit tests, the patients were seriously impaired in their ability to recollect the information consciously. The patients did not recollect the intact pairs more quickly than the recombined pairs nor did they make fewer errors in deciding that intact pairs had been previously presented (0.47%) than in deciding that recombined pairs had been presented (0.46%). This impaired performance stood in marked contrast to that of normal controls, who made 31% fewer errors and were 500 ms faster in processing intact pairs than recombined pairs. Despite this, the association-specific priming effect was greater in patients, even those who were severely amnesic, than in controls.

The larger association-specific priming effect in amnesic patients (109 ms) than in controls (23 ms) was unexpected. In principle, both conscious and unconscious processes should work in concert to produce an association-specific effect (e.g., Jacoby, 1996). Therefore, the impairment to conscious recollection should, if anything, reduce the magnitude of the effect that is observed in amnesic patients rather than enhance it. One possible interpretation of this finding is that the lexical-decision task, unlike other implicit memory tests, provides a measure of implicit associative memory that is relatively uncontaminated by explicit memory (Goshen-Gottstein & Moscovitch, 1995c) and that conscious recollection interferes with implicit memory in normal people.

Another interpretation, not incompatible with the first, is that the larger effect that is observed for amnesic patients does not represent any psychologically important phenomenon but, instead, represents an artifact of the overall response latencies of the two participant populations. Because amnesic patients were slower than controls in making lexical decisions, there was more room for repetition to aid performance. In conformity with this interpretation, we previously found (Goshen-Gottstein & Moscovitch, 1995b) that the magnitude of the association-specific repetition effect was dependent on word frequency, with high-frequency words, to which lexical decisions were fast, benefiting less from repetition than low-frequency words, to which lexical decisions were slow.

The most important conclusion from this study is that amnesic patients can acquire new associative information in a single trial. As such, it questions the validity of the relational-deficit hypothesis, which states that the amnesic syndrome is best characterized as an inability to form new relational associations among items (e.g., Cohen et al., 1997; Squire, 1992b, 1994). The ability of the patients in the present study to show intact associative memories on an implicit test, in conjunction with a gross impairment in recollecting these memories explicitly, contradicts the relational-deficit hypothesis.

The ability of amnesic patients to demonstrate association-specific priming effects likely depends on the perceptual nature of the simultaneous lexical-decision task (see also Gabrieli et al., 1997). Converging evidence from experiments on nonamnesic people suggests that the repetition effects that emerge when this task is used are perceptually based. First, the effects were mitigated when format of presentation was shifted across study and test (Goshen-Gottstein & Moscovitch, 1995c). Second, the effects were not sensitive to whether the word pairs were encoded by directing participants' attention to the meaning of the word pairs or to their surface features. Finally, the effects disappeared when the perceptual gestalt was not maintained across study and test. Thus, when study presentation was simultaneous, but test presentation was sequential, associative-priming effects were not found (Goshen-Gottstein & Moscovitch, 1995b).

Because of the perceptual nature of the associative effects and because the amnesic patients could not consciously recollect this information, we suggest that the effects were mediated by domain-specific perceptual representation systems (PRSs) or perceptual input modules, just as single-item repetition priming effects are. These systems process and retain presemantic structural information of stimuli as perceptual records (Moscovitch, 1992a, 1992b; Moscovitch & Umilta, 1990, 1991; Kirsner & Dunn, 1985; Schacter, 1990; Tulving & Schacter, 1990; Wiggs & Martin, 1998). Although these systems have typically been shown to represent information about single items, such as individual objects, words, and faces (e.g., Goshen-Gottstein & Ganel, in press), the findings in the current study suggest that also association-specific information may be represented in these perceptual systems.[1] Thus, despite the severe impairment of episodic recollection in amnesia, relational information can be stored, represented, and retrieved, if the correct conditions are satisfied. Together with our previous findings, the present study defines these conditions as those in which the perceptual gestalt of the relational information is maintained across study and test. It seems that once these conditions are met, amnesic and nonamnesic people alike can nonconsciously retrieve relational information.

The generality of these findings to different stimulus domains may depend on the nature of the PRS or input module that mediates performance. Whereas a word-form system may be designed to form new entities by combining elements, other systems may require the hippocampal complex to do so, whereas still others may not be suited for forming new implicit associations among its members. For example, systems implicated in representing spatial configurations may require the hippocampal complex for the formation of new associations, even on implicit tests of memory (Chun & Phelps, 1999). The face system, on the other hand, may be well suited for forming associations between different views of the same face to facilitate person recognition but not for forming implicit associations between faces of different individuals, even with an intact hippocampal complex. Indeed, in a series of experiments on normal people, Siegenthaler and Moscovitch (1999) found that associative priming for faces was obtained when a picture of an unfamiliar face taken from one viewpoint was paired with a picture of the same face taken from a different viewpoint but not when two different unfamiliar or familiar faces were paired with one another. Thus, the ability to form new associations may depend not only on creating an appropriate perceptual gestalt but also on the type of information that is to be bound together in memory.

[1] There may be a relation between the mechanisms that support associative priming in our studies and those that have been postulated to support conjunctive learning in nonhumans (Bunsey & Eichenbaum, 1996; Rudy & Sutherland, 1995; Whishaw & Tomie, 1991). At the moment, however, we believe that evidence of conjunctive learning in nonhumans is more akin to recent evidence of preserved explicit associative memory in some people with medial temporal lobe lesions (Holdstock et al., 1999). The animal studies resemble tests of recognition more than of priming. Because explicit associative memory was impaired in our population, it is unlikely that a common mechanism subserves both types of memory.

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