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WHEN PRIMING PERSISTS: LONG-LASTING IMPLICIT MEMORY FOR A SINGLE EPISODE IN AMNESIC PATIENTS*

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Abstract—This experiment investigated the durability of implicit memory for a single episode in normal and amnesic subjects. The target materials consisted of sentence puzzles that were difficult to comprehend in the absence of a key word or phrase. Sentences were re-presented at delays ranging from one minute to one week, and implicit memory was indicated by facilitation in solving previously incomprehensible sentences on subsequent exposures. Patients with severe memory impairments on tests of explicit recall and recognition showed substantial and robust facilitation, or priming, from a single prior presentation and there was no evidence of a systematic decay of facilitation over retention intervals up to one week. The long-lasting implicit memory observed in the sentence puzzle task contrasts with previous findings of rapid decay of priming effects in amnesic patients.

INTRODUCTION

MEMORY FOR an experienced event can be expressed either as conscious recollection or as a facilitation in performance that does not entail explicit retrieval of the learning experience. We refer to these types of memory performance as *explicit* and *implicit* memory, respectively [15, 30]. These descriptive labels distinguish between memory tasks that require subjects to make explicit reference to a particular study episode to express their learning, and those that do not. Performance on traditional recall and recognition tasks, which requires recollection of a past experience, falls within the domain of explicit memory. On implicit memory tests, no reference is made to a particular study episode. Subjects may be asked to complete a word fragment, spell a word, or identify a degraded or briefly exposed stimulus. Implicit memory for a recent episode is reflected by a facilitation or change in test performance that is referred to as a *priming effect* [6, 9]. Recent research has demonstrated that priming effects on implicit memory tests are uninfluenced by various encoding and retrieval manipulations that affect explicit memory [14, 17, 30, 35], and that the two types of memory performance can be statistically independent of one another [18, 35].

The distinction between implicit and explicit memory is relevant to understanding the preserved learning capabilities of patients with organic amnesia. Amnesic patients have severe difficulties remembering recent events on explicit memory tests. However, several studies have demonstrated that amnesic patients show normal or near-normal implicit

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memory for a recent episode under a variety of conditions. For example, WARRINGTON and WEISKRANTZ [37, 38] reported normal memory performance for amnesic patients when they were cued at recall with the initial letters of studied words. GRAF *et al.* [16] elaborated on this finding by examining implicit and explicit memory using the same initial letter cues for word completion and cued recall. They demonstrated that amnesic patients and normal controls showed equivalent levels of implicit memory (i.e., above-baseline completion of word beginnings with studied words), although control subjects performed far better than patients when instructed to use the same cues for explicit recall of the studied words. Similar findings of normal priming in amnesics have been reported for tasks involving spelling of homophones [18], word identification [5], lexical decision [22], free association [28, 32], and naming fragmented pictures and words [36, 37]. In all cases, the processes underlying implicit memory are apparently unaffected by the type of brain damage which produces gross impairments in explicit remembering. (For a demonstration of impaired implicit memory in severely amnesic patients, see [31].)

Although it is generally accepted that amnesic patients can show normal implicit memory following a single study episode, questions remain concerning the durability and persistence of the phenomenon. The facilitative effects of a study episode on test performance have typically been observed on tests administered within minutes or hours after initial exposure to the target materials. Moreover, several experiments have demonstrated that both amnesic and control subjects' word completion performance declines to baseline levels by two hours after study [11, 16, 32, 33]. Although there are cases in which priming of word fragment completion performance in normal subjects persists for days [35], amnesic patients have not shown long-lasting effects under these conditions [34]. These findings have prompted a number of theorists to propose than in amnesic patients, implicit memory is based upon a temporary activation of existing knowledge structures [11, 16, 20, 25].

There are several reasons, however, for suspecting that long-lasting implicit memory could be observed in amnesic patients. First, the negative findings in previous research may be partly a function of the types of tests employed. In virtually all cases in which implicit memory was shown to decay by two hours post-study, a single paradigm, word completion, was used (for an exception, see [32]). A second limitation of previous research is that most studies have used relatively impoverished materials, such as single words or word pairs. Finally, it is clear that amnesics do show long-lasting implicit memory in skill-learning and other tasks that typically involve extensive repetition of the target materials [4, 8, 12, 13, 21–23, 36]. These results suggest, but do not establish, that long-lasting implicit memory could be observed following a single study episode (see also [10]).

In light of these considerations, we investigated the possibility of long-lasting implicit memory for a single study episode in amnesic patients with a task that differs from paradigms used in previous research. The task involved solving and re-solving sentence puzzles that are difficult to comprehend without knowledge of a key word or phrase. These puzzles were taken from the studies of AUBLE and FRANKS [1, 2], who examined explicit recall of the sentences in college students. One example is, "The haystack was important because the cloth ripped". Although this sentence can be readily interpreted or solved when the word "parachute" is provided, it makes little or no sense when initially read. In the present experiment, subjects attempted to solve (i.e., produce the key word or idea) each sentence puzzle; if they did not produce the intended solution, it was provided. Sentences were then re-presented at various delays, and subjects again tried to solve them. The generation of sentence solutions need not entail conscious recall of prior study episodes. Accordingly, we reasoned that implicit memory of the puzzles would be indicated by facilitated solution of repeated items relative to baseline performance.

There are three reasons why amnesic patients may show durable implicit memory on this task. First, the target sentences are semantically richer and more elaborate than materials typically used in previous experiments, and it is known that some degree of semantic elaboration at the time of study is necessary to observe implicit memory under certain test conditions [30]. Second, unlike previous paradigms, subjects in our task are directed to engage in identical processing activities at study and test, a factor that can facilitate some expressions of implicit memory in normals [19]. Third, most of the sentences permit only a single solution; that is, only one idea or word makes sense of the puzzle. The use of word-completion cues that uniquely specify targets has been shown to facilitate long-lasting implicit memory with controls [35], although similar effects have not been observed in amnesics [34]. However, the use of single-solution puzzles, in conjunction with the other features of this task, may enhance the likelihood of observing long-lasting implicit memory in amnesic patients.

One important difference between the present experiment and other priming studies is that with the sentence-solution task it is difficult to prevent normal subjects' use of explicit memory. Previous research has demonstrated that an implicit memory test can be transformed into an explicit memory test by instructing normal subjects to invoke conscious retrieval strategies [16, 30]. In informal pilot testing with college students, we found it impossible to disguise the sentence task so that subjects did not invoke conscious retrieval to solve repeated sentence puzzles. Therefore, we expected that the control subjects in the present study would be able to draw upon explicit as well as implicit memory to solve or interpret the sentences, and thus show higher levels of solution performance than the amnesic patients. However, the critical question is whether amnesic patients can show long-lasting implicit memory for these solutions despite their impairment in explicit remembering. To address this question we sampled performance over a range of experimental conditions, defined by variations in the number of repetitions of sentence puzzles and the length of the retention interval between study and test.

METHOD

Subjects

Two amnesic patients with severe memory impairment, three patients characterized by more moderate memory deficits, and five control subjects, matched in terms of age and IQ, participated in the study. The amnesic patients were male and the control subjects were female, but we had no reason to suspect that this sex difference would influence the pattern of results. Relevant characteristics of the subjects are presented in Table 1. The patients had become amnesic as a result of various etiologies, and no patient was anomic, aphasic, or agnosic. One of the control subjects had experienced a mild head injury, but she had no measurable memory deficit. The remaining controls had no history of neurological dysfunction.

All amnesic patients displayed marked impairment on standard tests of recall, such as 30 min delayed recall of stories and hard associates from the Wechsler Memory Scale (WMS). There were, however, striking differences between the two patient groups which we believe reflect the severity of their memory deficits. First, test delay had a more marked effect on recall performance of the two patients whom we are calling severely amnesic than on the three patients whom we are calling moderately amnesic. For example, after 30 min the severely amnesic patients could not recall any information from the WMS and did not remember the occurrence of the initial presentation, whereas moderately amnesic patients could remember both the presentation episode and a small amount of the material. The groups' performance also differed on two tests of recognition memory: (1) a 2 hr delayed test of 16 pictures of complex scenes, and (2) an immediate test of 8 low frequency words. The two severely amnesic patients recognized virtually none of the studied items on either test, whereas the moderately amnesic patients were above chance on the verbal test and in the normal range for the complex scenes (Table 1). Additionally, the two severely amnesic patients

Table 1. Subject characteristics

Case No.	Diagnosis	Age	Education (years)	WAIS-R	WMQ	D-S	D-HA	Picture Recognition (Hits)	Picture Recognition (FA)	Word Recognition (Hits)	Word Recognition (FA)
Severely amnesic											
1.	Head injury	34	16	94	79	0	0	0	0	1	0
2.	Aneurysm	38	16	107	79	0	0	0	0	2	0
Mean		36	16	100.5	79						
Moderately amnesic											
3.	Head injury	26	12	89	82	1	0	14	0	5	1
4.	Temporal lobe abscess	47	15	100	84	3	1	15	0	6	0
5.	Hypoxia	49	20	112	89	3	1	12	1	5	0
Mean		40.7	15.7	100.3	85						
Control subjects											
1.		37	12	96	102	8	3	14	0	8	0
2.		23	15	98	108	6	4	14	1	8	0
3.	Head injury	23	15	93	106	6	4	14	0	8	0
4.		55	12	104	109	6	3	14	1	7	2
5.		48	12	109	132	8	4	16	1	8	0
Mean		37.2	13.2	100	111.4						

Note. D-S refers to delayed recall (30 min) of stories from WMS (max = 23); D-HA refers to delayed recall (30 min) of hard paired associates from WMS (max = 4). For picture recognition maximum hits and false alarms = 16; for word recognition maximum hits and false alarms = 8.

were unable to remember prior visits to our laboratory and could not recollect any recent episodes from everyday life. The three moderately amnesic patients could recollect previous visits and some recent personal experiences. In contrast to these striking differences, the disparity between IQ on the Wechsler Adult Intelligence Scale-Revised (WAIS-R) and MQ on the WMS, commonly taken as an index of severity of amnesia, does not reliably discriminate between our two patient groups (Table 1). However, questions have been raised regarding the validity of this difference score as an index of severity of amnesia [24, 30, 39]. In view of the marked performance disparities noted above, we thought it was prudent to distinguish between the moderately and severely amnesic patients and to analyze their data separately.

Materials

Twenty sentences and their solution key words were selected from the materials used by AUBLE and FRANKS [2]. These items were chosen from their list of "difficult" sentences, for which the average solution probability (i.e., comprehension of sentence in the absence of key words) was 0.12 for a group of 19 college students. Sentences were assigned to five four-item sets such that the average solution probability (from the AUBLE and FRANKS norms) for each set was similar (range 0.10 to 0.13). Five input orders of these sets were constructed, using a 5 × 5 Latin square (Table 2). One control and one amnesic subject was assigned to each presentation order. One patient had been exposed to two critical items prior to the experiment, so we constructed two replacement items for this patient, each presented in a different set.

Sixty additional sentences and their solution cues were used as recognition lures for the tests. Twenty of these were chosen from AUBLE and FRANKS' [2] list of "easy" sentences, and forty were generated for this study by the authors. These sentences had the same general properties as the critical items (i.e., a key word is needed to make sense of the sentence), although they were somewhat easier to solve than the critical items. Five sets of lures were constructed, each containing either 4, 8, 12, 16, or 20 items. Each set was assigned to a given delay condition, such that the number of repeated targets and new lures was equivalent at each delay. Finally, two sentences were constructed to serve as instructional examples, presented at each test, and two other sentences were used as fillers for the initial input session for all subjects.

Procedure

The same procedure was used for all sessions. General instructions about the nature of the task were followed by the two instructional examples. Subjects were told that they would be shown a number of sentences whose meaning would not be immediately apparent, but which could be solved or comprehended by thinking of a key word or phrase. For example, "the person was unhappy because the hole closed" became meaningful in the context of the phrase "pierced ears". Subjects were instructed to read each sentence aloud and try to come up with a solution within

Table 2. Schematic of experimental design. (Letter entries in table refer to particular 4-item target sentence sets)

Number of repetitions	Test delay 0	1 min	10 min	1 hr	24 hr	1 week
0	A	B	C	D	E	
1		A	B	C	D	E
2			A	B	C	D
3				A	B	C
4					A	B
5						A
No. of lures	0	4	8	12	16	20

60 sec. If they failed to generate the correct solution in the time allotted, the experimenter provided the key word(s), and requested an explanation of how the sentence made sense. When subjects generated an incorrect solution (e.g., "golf course", in the example above), they were told to continue trying for a "better" solution. For all delayed test sessions, subjects were informed that they had seen some items before, and were asked for a recognition judgment (yes or no) for each sentence after they had generated or been told the solution.

A schematic of the experimental design is presented in Table 2, with each entry in the table representing a set of four target items. In the first session (0 delay in Table 2), six sentences were presented for solution (e.g., set A and two fillers). After a 1 min filled delay, these A items, randomly intermixed with four sentences used for recognition lures, were re-presented. Subjects attempted to solve and make recognition decisions for each sentence. A new set of target sentences (B) was then introduced for solution, followed by the next retention interval. As the schematic illustrates, each delayed test session consisted of the re-presentation of all previously seen items, intermixed with an equivalent number of new lures, followed by presentation of a new set of target sentences. This procedure was employed for all sessions until the one week delayed test, at which no new items were introduced. With this design, new items introduced at the various sessions could be used to estimate baseline solution performance, priming and recognition for a single study episode could be evaluated over a number of delays, and effects of repetition on both solution performance and recognition could be assessed.

RESULTS

Sentence solutions

Baseline performance on the sentence task was calculated as proportion of solutions achieved on initial presentation of the target items. Baseline rates were virtually identical for severely amnesic patients (0.13), moderately amnesic patients (0.13), and controls (0.12).

The proportion of correct solutions for repeated items in the three subject groups is presented in Table 3. It is evident that patients' performance fluctuated considerably across experimental conditions, probably because of the small numbers of observations per condition. Nevertheless, statistical analysis of the data revealed a number of significant findings. All statistics are based on the BENNETT-FRANKLIN [3] non-parametric test for comparison of two proportions.

Consider first the data concerning the two severely amnesic patients. Solution performance for sentences given a single prior exposure is shown in the first row of Table 3. The mean proportion of correct solutions across all retention intervals was 0.48, which was significantly ($P<0.01$) above the baseline level. Solution accuracy, ranging from 0.25 to 0.63, exceeded baseline at all delays and there was no systematic effect of retention interval. Performance was as high when assessed after a week delay as it was after a 1 min delay. Thus, the severely amnesic patients showed robust implicit memory for a single study episode that lasted at least one week. Similar patterns of performance were observed at all levels of repetition. The effect of repetition on solutions can be examined either by following particular items over tests (on the diagonals of Table 3), or by collapsing across delays and comparing the row means in Table 3. Overall

Table 3. Proportion of correct solutions generated for severe amnesics (SA), moderate amnesics (MA), control subjects (CS)

Number of repetitions		Test Delay 1 min	10min	1 hr	24 hr	1 week	Mean
1	SA	0.50	0.25	0.63	0.38	0.63	0.48
	MA	0.67	0.75	0.50	0.42	0.33	0.55
	CS	1.00	0.95	1.00	0.85	0.70	0.90
2	SA		0.38	0.50	0.63	0.75	0.56
	MA		0.67	0.83	0.75	0.50	0.69
	CS		1.00	1.00	1.00	0.90	0.98
3	SA			0.38	0.63	0.63	0.54
	MA			0.75	0.58	0.58	0.64
	CS			1.00	1.00	1.00	1.00
4	SA				0.38	0.63	0.50
	MA				0.92	0.75	0.83
	CS				1.00	0.95	0.98
5	SA					0.63	0.63
	MA					0.92	0.92
	CS					1.00	1.00

there was no systematic effect of repetition on severely amnesic patients' performance. The difference between proportion of solutions generated after one (0.48) and after five (0.63) repetitions, though suggesting some effect of repetition, was not statistically reliable.

Moderately amnesic patients showed a different pattern of performance than did the severely amnesic patients. For once-presented items, there was evidence of a systematic decline in proportion of solutions attained as delay increased. Performance after 1 week delay (0.33) was significantly ($P<0.05$) lower than performance after a 1 min delay (0.67). There was also a strong effect of repetition: mean proportion of correct solutions increased from 0.55 after one prior presentation to 0.92 after five repetitions ($P<0.01$). Whereas the solution performance of the severely amnesic patients was unaffected by retention interval and repetition, the performance of the milder patients declined with increasing retention intervals and improved with repetition.

Control subjects' solution performance was significantly higher than that of both patient groups in most experimental conditions. For target items given a single prior exposure, controls' accuracy was nearly perfect at the shortest delays, but performance declined systematically with increases in retention interval, as indicated by a significant difference ($P<0.01$) between the proportion of solutions attained at the 1 min interval (1.00) and the 1 week delayed test (0.70). Repetition improved performance of control subjects; they solved significantly ($P<0.05$) more sentence puzzles after five repetitions than they did after a single prior exposure.

Recognition

Table 4 displays the proportion of hits for all delay and repetition conditions and the proportion of false alarms for each session. There was a striking difference in recognition performance between severely and moderately amnesic patients. The severely amnesic patients consistently failed to recognize any items, although one patient did recognize a single sentence after four prior presentations. Moreover, these patients consistently failed to recollect that they had previously performed the task, even after several sessions. Moderately amnesic patients, on the other hand, showed perfect recognition for once-presented items at the early test delays and showed substantial levels of recognition at the 24 hr and 1 week test delays, although performance declined markedly with respect to the earlier delay conditions. Recognition improved somewhat with repetition for these patients, although they still performed much worse than controls at the longest delay. The moderately amnesic patients had no difficulty remembering that they had previously performed the sentence puzzle task. Recognition for control subjects was nearly perfect in all conditions.

Table 4. Recognition accuracy (proportion of hits) for severe amnesics (SA), moderate amnesics (MA), and control subjects (S). (False alarms (FA) are presented in the final three rows)

Number of repetitions		Test delay 1 min	10 min	1 hr	24 hr	1 week	Mean
1	SA	0.00	0.00	0.00	0.00	0.00	0.00
	MA	1.00	1.00	1.00	0.58	0.67	0.85
	CS	1.00	1.00	1.00	1.00	1.00	1.00
2	SA		0.00	0.00	0.00	0.00	0.00
	MA		1.00	1.00	1.00	0.83	0.96
	CS		1.00	1.00	1.00	1.00	1.00
3	SA			0.00	0.00	0.00	0.00
	MA			1.00	0.92	0.83	0.92
	CS			1.00	1.00	1.00	1.00
4	SA				0.12	0.12	0.12
	MA				1.00	0.83	0.92
	CS				1.00	1.00	1.00
5	SA					0.12	0.12
	MA					0.83	0.83
	CS					1.00	1.00
FA	SA	0.00	0.00	0.00	0.00	0.00	
	MA	0.08	0.00	0.00	0.06	0.18	
	CS	0.00	0.00	0.00	0.00	0.04	

A dissociation between implicit memory and explicit recognition is evident when patterns of performance are compared across subject groups. The proportion of solutions attained by the moderately and severely amnesic patients was similar, despite marked differences in their recognition performance. Although severely amnesic patients neither recalled the task nor recognised the sentences, they nevertheless generated nearly as many correct solutions for once-repeated sentences as did the moderately amnesic patients, who clearly remembered many items and aspects of the task. Unfortunately, we could not perform a meaningful contingency analysis to assess statistical independence between recognition and priming [18, 35], because most of the recognition data was either on the ceiling or floor.

DISCUSSION

The results of the present experiment document long-lasting implicit memory for a single episode in amnesic patients.* When solving repeated sentence puzzles, severely amnesic

*As we were completing this paper, we learned that DOBBS and PARKER (unpublished observations, 1986) have found similar results with different types of sentence puzzles.

patients showed substantial performance facilitations that remained relatively constant over retention intervals ranging from 1 min to 1 week, even for items given only a single prior exposure. These patients showed robust implicit memory despite their complete lack of explicit recognition of the target materials, a dissociation that is consistent with results of previous studies [5, 16, 18, 28, 34, 36–38]. Patients with milder memory impairments displayed a pattern of performance similar to control subjects, showing large performance facilitations that declined across increasing retention intervals.

Unlike previous studies, performance on the implicit task in this experiment was, in most conditions, higher for control subjects than for amnesic patients. It seems likely that control subjects and patients with moderate memory deficits were able to augment their solution performance by using explicit memory for the previously presented target items. Explicit memory should be most effective at short retention intervals, but would be expected to decline with increasing delays. Results of both the recognition task and the sentence-solution task conformed to this pattern in the control and moderately amnesic groups. In addition, the moderately amnesic patients performed at a lower level than controls, a finding that is consistent with the notion that these patients may have been relying, at least in part, on an impaired explicit memory to perform the task. In marked contrast to these findings were the patterns of performance for severely amnesic patients, who displayed substantial facilitation with no decrements in performance over the 1 week delay and no evidence of recognition of the target materials. Although we could not tease apart the separate contributions of explicit and implicit memory to solution performance in the less impaired groups, performance in the severely amnesic patients appeared to be uncontaminated by any influence of explicit memory (for discussion of a similar point, see [7, 21, 27]).

The primary contribution of the present experiment is the demonstation that implicit memory of a single episode in severely amnesic patients does not necessarily decay in a few hours [10]. Based on previous findings of rapid decay of facilitation [4, 9, 30], it has been suggested that implicit memory for a single episode in amnesic patients reflects a temporary activation of existing representations [5, 11, 34]. Such short-lived activation, however, is unable to account for the present results.

How can we conceptualize the long-lasting implicit memory observed in this experiment and relate it to other evidence that favors the notion of temporary activation? We can begin by noting that the observation of long-lasting implicit memory need not be used as grounds for rejecting entirely an activation view. As has been suggested elsewhere [29, 31, 34], it is possible that there are different types of implicit memory, and that temporary activation of pre-existing representations constitutes just one basis for implicit memory of a single episode. Though we acknowledge that activation plays some role in implicit memory, our data indicate that something more than transient activation is involved. Recent ideas advanced by RUMELHART and NORMAN [26] may help to provide some insight into the phenomenon that we have observed.

RUMELHART and NORMAN [26] discussed a type of learning that they called *restructuring:* a relatively permanent modification or "re-wiring" of the organizational structures of memory. Restructuring occurs when existing memory structures are not adequate to accommodate or make sense of new information. When presented with information that is not readily understood, new interpretive structures are created by a reorganization of existing memory schemas. Such a restructuring process may have been invoked by our sentence puzzle task. Presentation of solutions in the context of incomprehensible sentence puzzles may have promoted a rapid restructuring of subjects' stored knowledge to produce a new, integrated memory representation, which can then support interpretation of sentences such as "The haystack was important because the cloth ripped". This new structure can be contacted by the sentence puzzle on subsequent presentations, even when the subject has no explicit recollection of the original study episode and when relatively long delays are interposed between successive presentations.

An additional feature of the current study is also consistent with RUMELHART and NORMAN's [26] description of restructuring. They argue that this process often seems to be accompanied by a "click of comprehension"—a feeling of insight or understanding into a previously incomprehensible puzzle. This description is strikingly similar to the mechanism that AUBLE and FRANKS [2] proposed to account for explicit recall of the sentence puzzles. Auble and Franks argued that recall was facilitated by an "aha" experience (a state of noncomprehension followed by comprehension of the sentence), which provided memorial benefits above and beyond those attributable to semantic elaboration. Our data appear to indicate that the restructuring processes leading to such an "aha" experience are responsible not only for good explicit recall, but also for durable implicit memory. We suggest that previous priming research which supported the temporary activation hypothesis failed to demonstrate long-lasting implicit memory in amnesic patients because the conditions of the experiments did not allow rapid restructuring to occur. Explication of the sufficient conditions for invoking this process, and understanding the nature of the restructuring process itself, are matters for further research. The present results, however, suggest that severely amnesic patients are capable of this mode of learning and that their implicit memory for the outcome of the restructuring process is reliable and persistent.

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