ACQUISITION AND TRANSFER OF DECLARATIVE AND PROCEDURAL KNOWLEDGE BY MEMORY-IMPAIRED PATIENTS: A COMPUTER DATA-ENTRY TASK

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Abstract—Previous research demonstrated that a single amnesic patient could acquire complex knowledge and processes required for the performance of a computer data-entry task. The present study extends the earlier work to a larger group of brain-damaged patients with memory disorders of varying severity and of various etiologies and with other accompanying cognitive deficits. All patients were able to learn both the data-entry procedures and the factual information associated with the task. Declarative knowledge was acquired by patients at a much slower rate than normal whereas procedural learning proceeded at approximately the same rate in patients and control subjects. Patients also showed evidence of transfer of declarative knowledge to the procedural task, as well as transfer of the data-entry procedures across changes in materials.

INTRODUCTION

Considerable evidence has confirmed that the memory deficit associated with various kinds of neurological insult is not global but instead is selective: some forms of memory are lost or damaged while others remain intact. For example, amnesic patients can acquire a variety of motor, cognitive and perceptual skills in a normal or near-normal fashion although they may have little or no recollection of the learning episodes [2, 5, 6, 19, 20]. Amnesic patients also exhibit normal repetition priming: they are as likely as normal subjects to demonstrate the effects of recent experiences with words, pictures, melodies, novel objects and dot patterns although they fail to remember the prior experience [4, 7, 8, 17, 22, 30, 31].

Despite numerous demonstrations of the contrasts between preserved and impaired memory functions in amnesic patients, theorists have not agreed on the best way to characterize this distinction. Some investigators have proposed that the amnesic deficit represents a selective impairment of episodic memory with relative sparing of semantic memory [18, 32]. Others such as Squire [27] and his colleagues [6, 25] have suggested that amnesic patients cannot easily acquire "declarative" or factual knowledge but can acquire "procedural" and other non-declarative forms of knowledge in a normal fashion. Graf and Schacter [14, 23] have postulated that "implicit" memory, which does not rely on conscious retrieval of prior episodes, is spared in amnesia while "explicit" memory, which requires awareness of past occurrence, is impaired. This latter distinction makes no direct reference to the content of the preserved memories and therefore does not rule out the possibility that factual information might be acquired by memory-impaired patients in an implicit fashion—that is, without conscious recollection of the learning experiences. Similarly, Squire's
distinction leaves open the possibility that, although amnesic patients have difficulty acquiring new facts via a damaged declarative memory, such information may be able to be learned through non-declarative means. In either case, a question of interest concerns whether declarative knowledge can be acquired "normally" through implicit means, or whether the procedural or implicit memory systems will be slow and inefficient when processing factual information.

**Glisky and colleagues [10, 12, 13] explored the acquisition of declarative knowledge by amnesic patients in a series of experiments in which they attempted to teach patients complex knowledge within a specific domain. These studies attempted to capitalize on patients' preserved implicit memory abilities—specifically, the ability to produce previously-exposed words to partial cues. Many studies have demonstrated that amnesic patients, when provided with word-stem cues such as WIN and instructed to say the first word that comes to mind, are as likely as normal subjects to produce a previously-exposed word (e.g. WINDOW) rather than words not seen previously (e.g. WINTER, WINDMILL, WINCH, etc.).** **Glisky et al. [13] hypothesized that repeated priming of responses might produce more durable memory representations that might eventually support long-term retention of declarative knowledge.**

To adapt the priming paradigm for these purposes, they devised a training technique, *the method of vanishing cues*, which provides partial letter information for target responses and then gradually withdraws it across learning trials. Using this technique, memory-impaired patients were able to learn 10–15 items of new computer-related vocabulary, which they were able to produce to definitions in the absence of letter cues and retain over a 6-week interval [13]. Their learning, however, was not normal. They took much longer than control subjects to acquire the vocabulary and their knowledge seemed to be *hyperspecific*: They were much less able than normal subjects to produce the words when the definitional cues were altered on a transfer test. Although patients were apparently able to acquire "declarative" information through implicit means, the information so acquired may have been represented differently than declarative knowledge acquired through normal explicit memory processes.

The authors speculated that patients' learning may have been stored as a series of isolated stimulus–response bonds that were not well-integrated with other knowledge structures. Normal subjects, on the other hand, may have engaged in more elaborative processing, forging connections to prior knowledge, and creating elaborate representations that supported good transfer. The reported finding that normal subjects are not helped by the method of vanishing cues is consistent with the view that the technique taps intact implicit processes in memory-impaired patients. Normal subjects rely on explicit memory to acquire new knowledge and thus gain no advantage from the vanishing cues technique.

A further experiment [12] examined whether memory-impaired patients, using the method of vanishing cues, could acquire complex forms of knowledge that were unlikely to be represented as simple stimulus–response connections. In this study, patients were taught how to operate a microcomputer. Although patients successfully learned to perform various computer functions (e.g. storing and retrieving information from a disk, writing and editing simple computer programs), their knowledge was again characterized by hyperspecificity: patients had difficulty accessing what they had learned in changed or unconstrained contexts; normal control subjects had no such problems.

**Shimamura and Squire [25] suggested that the knowledge acquired by patients in these computer learning experiments was largely procedural, and that procedural knowledge is, by definition, domain-specific, inflexible, and not easily accessed in altered contexts [27].**
Acquisition of procedural knowledge also often proceeds at a normal rate in amnesic patients; however, this was clearly not the case in the computer learning studies. Nevertheless, it is still possible that amnesic patients represent declarative knowledge, such as vocabulary, in procedural form and that this form of learning is a relatively slow and inefficient process. It is also not clear that amnesic patients would necessarily show hyperspecificity or lack of transfer in the learning of a procedural task. 

Charles et al. [26] have demonstrated that a Korsakoff patient, following the learning of a mathematical rule, showed less specificity in a transfer task than normal subjects. They argued that the patient was unable to "proceduralize" the learning of rules to the same extent as control subjects and was thereby able to apply the rule flexibly to new problems. The issues with respect to the acquisition and transfer of both declarative and procedural learning in amnesic patients, therefore, are as yet far from clear.

In an effort to gain further understanding of the variables that contribute to hyperspecificity in amnesic patients and to investigate limitations on transfer from the laboratory to everyday life, Glisky and Schacter [9] attempted to train an amnesic patient, H.D., for a real-world job in computer data-entry. Training was divided into two phases—a knowledge acquisition phase in which 28 pieces of declarative information concerning the task had to be learned, and a skill acquisition phase, in which the actual data-entry procedures were acquired. Training took place in the laboratory with a careful simulation of the real-world job, the training technique was the method of vanishing cues.

In the knowledge acquisition phase of the study, H.D. needed 60 letter hints and took 56 min to complete the first trial. However, she was able to achieve perfect performance without any hints after 27 trials, at which time she completed a trial in about 10 min. When H.D. began the actual data-entry procedures in the skill acquisition phase of training, she made few errors and rapidly improved her speed of data-entry over a period of 5 weeks. H.D.'s subsequent transition into the workplace was also smooth; she made few errors and by the second day on the job was performing the task as quickly as in the laboratory. Successful transfer into the workplace was thus achieved. The authors attributed the successful learning and transfer of the data-entry task to a number of factors: (a) the job was closely simulated in the laboratory; (b) the procedures once learned were invariant over time and materials; (c) although the documents for the data-entry task differed with respect to the particular numbers to be extracted, all documents were similar in overall appearance and relevant information appeared in the same location on all documents. The general procedures that had to be performed were identical in all cases; only the specific data changed.

The results of this study demonstrated that an amnesic patient could acquire complex knowledge and procedures in the laboratory and apply them to similar materials in an important domain of everyday life—the workplace. Several questions, however, remained unanswered: First, did learning proceed at a normal rate and was there evidence of hyperspecificity? These questions could not be addressed because no control subjects were tested. Another question concerned whether there was something special about patient H.D. that enabled her excellent performance in this task.

The present experiment was designed to address these questions as well as to obtain more evidence concerning the acquisition and transfer of declarative and procedural information. H.D. was a patient who had become severely amnesic as a result of herpes simplex encephalitis. Her performance on the Wechsler Memory Scale of 65 was well below her IQ of 84 obtained on the WAIS—R and indicated substantial impairment. Nevertheless, she retained excellent attentional skills, which may have contributed to her success in the data-
entry task. For example, she attained six categories on the Wisconsin Card Sorting Test with few perseverations, and she showed no signs of distractibility when working on the computer tasks. Because many brain-damaged patients with memory problems have frontal lobe damage, they may lack the concentration to learn complex tasks such as data-entry. In order to test the generality of the findings obtained with H.D., a laboratory analog of the computer data-entry tasks was devised, and several memory-impaired patients were tested. The task was identical to the laboratory training portion of the data-entry task learned by H.D. except that the documents used during training were laboratory imitations rather than real company documents. Also transfer to the workplace could not be assessed. Instead, two laboratory transfer tests were devised.

METHODS

Subjects

Ten patients with memory disorders of varying degrees of severity and of various etiologies participated in the experiment, along with five normal control subjects. All patients were at least 1 year post-trauma. Key characteristics of the participants appear in Table 1. Half of the patient group had suffered closed head injuries (CHI). Of these, three patients (M.R., M.C. and J.L.), exhibited substantial intellectual impairment in addition to their memory deficits, and all of the CHI patients except V.R. had some degree of motor impairment. The other five patients had suffered brain damage as a result of aneurysm, encephalitis or anoxia. None of these patients showed significant intellectual deterioration or motor impairment with the exception of W.D. whose IQ was in the Low Average range and who had a right-sided weakness. Eight of the 10 patients (excluding D.L. and C.W.) showed evidence of frontal lobe damage as documented by brain scans and/or neuropsychological test scores. The mean measure of general memory ability obtained from the Wechsler Memory Scale—Revised was 73.9 for patients, which was on average 21.2 points below their mean IQ score of 95.1 obtained from the WAIS—R. The severity of memory disorders, however, was quite variable. Patients V.R. and D.L. were considered to have mild memory disorders, although these patients were dysfunctional in vocational contexts. The other patients' memory disorders were classified as moderate to severe; none were employed.

<table>
<thead>
<tr>
<th>Table 1. Subject characteristics</th>
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<tbody>
<tr>
<td>Diagnosis*</td>
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<tr>
<td>Patients</td>
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<tr>
<td>C.C.</td>
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<td>V.R.</td>
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<tr>
<td>M.R.</td>
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<td>M.C.</td>
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<td>J.L.</td>
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<td>W.D.</td>
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<tr>
<td>B.R.</td>
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<tr>
<td>D.T.</td>
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<tr>
<td>C.W.</td>
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<tr>
<td>D.H.</td>
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<tr>
<td>Mean (N = 10)</td>
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<tr>
<td>H.D.</td>
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<tr>
<td>Controls</td>
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<tr>
<td>J.N.</td>
</tr>
<tr>
<td>J.U.</td>
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<tr>
<td>J.S.</td>
</tr>
<tr>
<td>D.C.</td>
</tr>
<tr>
<td>B.Y.</td>
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<tr>
<td>Mean (N = 5)</td>
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</table>

*CHI = closed head injury, ACAA = anterior communicating artery aneurysm.
The control subjects did not differ significantly from the patients in age or IQ, but they performed at significantly higher levels on tests of memory function.

Materials and apparatus

The task to be learned was a computer data-entry job that required subjects to extract information from company documents called "meter cards" and enter it into a 9-column coded computer display. Three hundred meter cards were constructed; they were all similar in appearance and relevant information appeared in the same location on all cards: specific numbers and dates, however, varied across cards. The pertinent information consisted of a 6-digit customer number located under a heading CUST NO., an 8-digit document number shown on the card as SERIAL NO., a 4-digit roll number, a 6-digit record number (which was the same on all cards), and a date, which was handwritten in the top right corner of the card. Other irrelevant numbers and dates appeared randomly in various locations across cards. (For a more detailed description of the task, see Ref. [9].)

The computer display into which information was to be entered consisted of nine, coded, column headings, seven of which were used and two of which remained blank. Information from a single card was entered into one row of the display and constituted a record. The five relevant numbers were entered into five of the columns; the letters A and MC, which were the same for all records, had to be typed into two of the other columns; TAB and RETURN were used in the blank fields.

Subjects were trained on a specially-adapted Apple IIe microcomputer, which included a numeric keyboard embedded in the right hand side of the alphabetic keyboard. These specialized keys were programmed to produce letters (e.g., M) when typing in an alphabetic field and numbers (e.g., 7) when in a numeric field.

Procedure

Basic training was divided into three phases: a knowledge acquisition phase in which declarative information concerning the data-entry task was taught, a skill acquisition phase, in which the actual data-entry procedures were performed, and a transfer phase, in which the data-entry procedures were performed under slightly altered stimulus conditions.

Knowledge acquisition. In the knowledge acquisition phase, subjects were presented with 28 incomplete sentences, and were required to type the correct completions on the computer keyboard. The sentences defined the important terminology associated with the job, explained the meanings of the coded column headings, described the location and key identifying features of relevant information on the cards, delineated the mapping between the cards and the display, and illustrated how and where critical information was to be entered. Subjects did not, in this phase of training, carry out any of the data-entry procedures. They simply completed the sentences with the critical target words.

Training was by the method of vanishing cues. On the first training trial, subjects were given as many letter cues as they needed to complete the target word correctly. For example, for the sentence "The information from one document is entered into a single row and is called a __", letter cues were added one at a time until the subject generated the correct response (i.e., R, RE, REC, RECO...RECORD). Letter cues were then "vanished" gradually across trials (i.e., REC, RE, R) until eventually no cues were provided. If on any trial the subject was unable to produce the correct response, letters were added back as needed. A different meter card was used on each trial so that the critical numeric information was constantly changing.

Two 2-hr training sessions were conducted each week and subjects continued until they correctly completed two consecutive trials without any letter cues. The dependent measures were the number of trials to criterion, the number of letter cues per trial, and the time to complete each trial.

Skill acquisition. At the completion of the knowledge acquisition segment of training, subjects had acquired all the declarative information needed to perform the data-entry task. They then entered the skill acquisition phase, in which they actually executed the data-entry procedures. Although subjects had learned the facts associated with the task, they had not actually performed any of the data-entry operations during the first phase of training. The skill acquisition task thus represented a kind of transfer situation whereby declarative information learned in the first part of the experiment could be used to facilitate performance. In this segment of training, subjects were simply handed a stack of cards and told to enter them into the computer display. There were three parts to the training.

In Part I, the basic data-entry procedures were learned. Subjects were required to enter data from 10 cards onto a single screen (one card per row) on each trial; 25 trials were completed in Part I (except for V.R. who completed only 10).

Part II introduced two simplifications of the procedure, which were intended to increase speed and efficiency of data-entry. Because the roll number was the same for all cards, it could be entered only once at the bottom of the screen. In addition, a special ENTER key had to be pressed at the end of each trial, ostensibly to send an entire screenful of data to the mainframe computer at one time. Subjects were informed verbally of these changes. Twenty trials were included in Part II. If subjects made errors in the first two parts of skill acquisition, initial letters or numbers of target responses were provided as cues.

In Part III, no cues were available; subjects were required to correct any errors on their own. Twenty records (i.e., cards) constituted one trial and subjects completed 40 trials.

In all parts of skill training, subjects came to the laboratory twice a week for a 2-hr session, during which time they
completed as many trials as time would permit. At the end of training, subjects were given a 4-week break, and then returned to the laboratory for a single data-entry session. The dependent measures for the skill acquisition phase of training were cues per trial (Parts I and II) and mean times (in secs) to enter a single record (i.e. data for one card).

Transfer phase. Two transfer tests were devised to examine the extent to which the procedures learned would transfer across relatively minor changes in materials—the kinds of changes that might reasonably be expected to occur in a real-world job situation. In Transfer Task A, two of the descriptive headings on the meter cards, CUST. NO. and SERIAL NO. were omitted from the cards; in Task B, in addition to the omitted headings, the locations of the two numbers (i.e. those corresponding to CUST NO. and SERIAL NO.) were reversed on the cards.

Prior to each transfer task, subjects completed two 10-card trials with “normal” cards (as in Part II of skill acquisition) to establish a baseline level of performance. This was necessary because patients always showed a warm-up effect at the start of each session, and furthermore subjects had not achieved entirely stable levels of performance: some improvements continued to be noted. Subjects were then given the transfer tests, were informed of the nature of the changes on the “abnormal” cards, and were instructed to enter the data from these cards into the computer display as before. Two 10-card trials were given. The number of cues and times per card were recorded.

RESULTS

Knowledge acquisition

The results from the knowledge acquisition phase of the study are shown in Table 2. Data for H.D., the case study patient, are included in this and other tables for comparison purposes. All patients were able to acquire the factual information associated with the data-entry task. Although they were extremely variable in the number of letter cues that they required to complete the sentences initially, they all (with one minor exception) were eventually able to produce the target responses without any cues. They differed substantially, however, in the number of trials needed to reach criterion. The mildly-impaired patients V.R. and D.L. and the moderately-impaired patient C.C. acquired the knowledge as readily as control subjects. All of the other patients, however, required many more trials than normal to achieve perfect levels of performance.

<table>
<thead>
<tr>
<th>Patients</th>
<th>Trials to criterion</th>
<th>Letter cues per trial</th>
<th>Times per trial (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C.C.</td>
<td>15</td>
<td>42 0</td>
<td>41.4 11.6</td>
</tr>
<tr>
<td>V.R.</td>
<td>9</td>
<td>41 0</td>
<td>18.6 6.4</td>
</tr>
<tr>
<td>M.R.</td>
<td>50</td>
<td>106 0</td>
<td>114.4 25.7</td>
</tr>
<tr>
<td>M.C.</td>
<td>61</td>
<td>167 0</td>
<td>50.0 9.3</td>
</tr>
<tr>
<td>J.L.</td>
<td>114</td>
<td>101 0</td>
<td>70.3 10.6</td>
</tr>
<tr>
<td>W.D.</td>
<td>79</td>
<td>107 1</td>
<td>79.0 10.1</td>
</tr>
<tr>
<td>B.R.</td>
<td>125</td>
<td>92 0</td>
<td>62.0 7.2</td>
</tr>
<tr>
<td>D.L.</td>
<td>15</td>
<td>56 0</td>
<td>19.9 5.9</td>
</tr>
<tr>
<td>C.W.</td>
<td>180</td>
<td>153 0</td>
<td>87.7 9.1</td>
</tr>
<tr>
<td>D.H.</td>
<td>198</td>
<td>118 0</td>
<td>69.7 13.5</td>
</tr>
<tr>
<td>Mean (N = 10)</td>
<td>84.6 98 3 0</td>
<td>61.3 10.9</td>
<td></td>
</tr>
<tr>
<td>H.D.</td>
<td>27</td>
<td>60 0</td>
<td>55.5 9.9</td>
</tr>
<tr>
<td>Controls</td>
<td>J.N. 20</td>
<td>79 0</td>
<td>50.4 7.8</td>
</tr>
<tr>
<td>J.U.</td>
<td>15</td>
<td>66 0</td>
<td>23.8 5.3</td>
</tr>
<tr>
<td>J.S.</td>
<td>17</td>
<td>97 0</td>
<td>19.8 7.4</td>
</tr>
<tr>
<td>D.C.</td>
<td>19</td>
<td>106 0</td>
<td>20.3 6.3</td>
</tr>
<tr>
<td>B.Y.</td>
<td>24</td>
<td>94 0</td>
<td>32.4 6.0</td>
</tr>
<tr>
<td>Mean (N = 5)</td>
<td>19.0 88.4 0</td>
<td>29.3 6.6</td>
<td></td>
</tr>
</tbody>
</table>
The statistical comparisons reported in this paper are all based on unweighted means analysis because of the unequal sample sizes and heterogeneity of variance. The test statistic reported for the comparisons between patients and control subjects is the approximate t, which uses unpooled variances. In addition, the Welch–Satterthwaite correction (see Ref. [16]) was applied to reduce degrees of freedom and thereby provide a more stringent test of significance. When this test statistic is used, it will be reported as t'.

As a group, patients were significantly impaired relative to normal subjects, requiring on the average 84.6 trials to reach criterion compared to 19 trials for control subjects, t' (9.1) = 3.04, P = 0.014. Patients also took significantly longer than normal subjects to complete the first learning trial—61.3 min compared to 29.3 min—t' (12.9) = 2.89, P = 0.013, and the final learning trial—10.9 min compared to 6.6 min—t' (10.1) = 2.36, P = 0.04. The two groups did not differ reliably in the number of letter cues required on the initial trial (98.3 and 88.4).

Skill acquisition

Results of the skill acquisition phase of training are outlined in Table 3. The left side of the table shows the number of cues required per trial in Part I and the number of trials needed to reduce those cues to zero. Most of the patients were able to perform the data-entry task with only a few hints. On each trial, a total of 90 entries was required (i.e. 9 responses for each card × 10 cards). As a group the patients initially needed slightly more cues than control subjects (6.8 vs 3.8), a difference that was not significant, t' (11.3) = 1.86, P = 0.089. However, patients’ errors, although few, persisted for more trials than those of normal subjects (7.4 vs 2.4), t' (10) = 2.96, P = 0.014. Note also that the three patients with the mildest impairments, V.R., D.L. and C.C., all performed as well or better than normal subjects.

<table>
<thead>
<tr>
<th>Patients</th>
<th>Part I</th>
<th>Mean times per card (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Letter cues per trial</td>
<td>Trials to 0 cues</td>
</tr>
<tr>
<td>C.C.</td>
<td>0-0</td>
<td>1</td>
</tr>
<tr>
<td>V.R.</td>
<td>3-0</td>
<td>3</td>
</tr>
<tr>
<td>M.R.</td>
<td>7-0</td>
<td>2</td>
</tr>
<tr>
<td>M.C.</td>
<td>13-0</td>
<td>10</td>
</tr>
<tr>
<td>J. L.</td>
<td>8-0</td>
<td>12</td>
</tr>
<tr>
<td>W.D.</td>
<td>6-0</td>
<td>12</td>
</tr>
<tr>
<td>B. R.</td>
<td>13-0</td>
<td>15</td>
</tr>
<tr>
<td>D. L.</td>
<td>0-0</td>
<td>1</td>
</tr>
<tr>
<td>C. W.</td>
<td>11-0</td>
<td>9</td>
</tr>
<tr>
<td>D. H.</td>
<td>7-0</td>
<td>9</td>
</tr>
<tr>
<td>Mean (N = 10)</td>
<td>6.8-0</td>
<td>7.4</td>
</tr>
<tr>
<td>H. D.</td>
<td>3-0</td>
<td>3</td>
</tr>
<tr>
<td>Controls</td>
<td></td>
<td></td>
</tr>
<tr>
<td>J. N.</td>
<td>4-0</td>
<td>2</td>
</tr>
<tr>
<td>J. U.</td>
<td>3-0</td>
<td>3</td>
</tr>
<tr>
<td>J. S.</td>
<td>3-0</td>
<td>3</td>
</tr>
<tr>
<td>D. C.</td>
<td>3-0</td>
<td>1</td>
</tr>
<tr>
<td>B. Y.</td>
<td>6-0</td>
<td>3</td>
</tr>
<tr>
<td>Mean (N = 5)</td>
<td>3.8-0</td>
<td>2.4</td>
</tr>
</tbody>
</table>
Patients performed the data-entry task more slowly than normal subjects across all trials. As can be seen on the right side of Table 3, patients took, on the average, 131.4 sec to enter data from a single card on the first trial of Part I, whereas control subjects needed only 50.1 sec, \( t' (10.2) = 4.04, P < 0.01 \). Both groups, however, appeared to improve at about the same rate; after 25 trials (i.e. by the end of Part I) their speed of data-entry increased by approximately 50%.

In Part II of skill acquisition, very few hints were needed initially and perfect performance was achieved rapidly by all subjects. Subjects showed slowing relative to finishing times in Part I while they adapted to the two new procedures, but by the end of 20 trials, speeds had increased still further so that both groups of subjects were approximately 15% faster by the end of Part II than they were at the conclusion of Part I.

Across the 40 trials of Part III, data-entry times continued to improve. The second column from the right shows the mean time to enter data from a single card during the last session of Part III: the last column displays performance after a 1 month retention interval. The performance of both patients and control subjects was somewhat slower after the 4-week delay. A 2 \( \times \) 2 ANOVA, however, revealed no significant differences between performance in the last regular data-entry session and the delay session \( [F (1, 13)= 2.38, MS_e = 94.4, P > 0.14] \) and no interaction with group.

Transfer
Results of the transfer test are shown in Table 4. The number of letter cues required for correct responding (shown in parentheses) was very small and did not differ significantly across groups or conditions. Table 4 displays the mean times required to enter data from a single card during the second baseline trial and on the transfer trials. A 2 \( \times \) 2 \( \times \) 2 ANOVA comparing performance on the first transfer trial to baseline indicated a main effect of group \( [F (1, 13)= 4.64, MS_e = 3095.1, P = 0.05] \), a difference between baseline and the first transfer trial \( [F (1, 39) = 18.9, MS_e = 51.4, P < 0.001] \), and an interaction between these two factors \( [F (1, 39) = 5.20, MS_e = 51.4, P = 0.028] \). There were no other significant effects. As can be seen in Table 4, all subjects' data-entry performance slowed significantly in the transfer tasks relative to baseline and the slowing was greater for patients than for control subjects. Speed of performance on a second transfer trial (i.e. Transfer 2 in Table 4), however, increased considerably and approached baseline once again. Although an ANOVA indicated that performance on the second transfer trial was still significantly slower than baseline \( [F (1, 13)= 18.7, MS_e = 38.4, P < 0.001] \), the difference was the same for both groups of subjects, \( F < 1 \). Patients thus appeared to adapt to the demands of the transfer task as readily as control subjects.

<p>| Table 4. Mean data-entry times per card (in sec) in two transfer tasks (A and B), compared to baseline entry times. Mean number of cues per 10 cards are shown in parentheses. |
|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|</p>
<table>
<thead>
<tr>
<th>Baseline</th>
<th>Transfer 1</th>
<th>Transfer 2</th>
<th>Baseline</th>
<th>Transfer 1</th>
<th>Transfer 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients</td>
<td>50.8 (0.1)</td>
<td>58.5 (0.4)</td>
<td>53.2 (0.8)</td>
<td>49.0 (0.4)</td>
<td>67.4 (1.9)</td>
</tr>
<tr>
<td>Controls</td>
<td>21.3 (0.2)</td>
<td>24.1 (0)</td>
<td>24.0 (0.2)</td>
<td>21.8 (0)</td>
<td>27.1 (0.2)</td>
</tr>
</tbody>
</table>

seen in Table 4, all subjects' data-entry performance slowed significantly in the transfer tasks relative to baseline and the slowing was greater for patients than for control subjects. Speed of performance on a second transfer trial (i.e. Transfer 2 in Table 4), however, increased considerably and approached baseline once again. Although an ANOVA indicated that performance on the second transfer trial was still significantly slower than baseline \( [F (1, 13)= 18.7, MS_e = 38.4, P < 0.001] \), the difference was the same for both groups of subjects, \( F < 1 \). Patients thus appeared to adapt to the demands of the transfer task as readily as control subjects.
The present study demonstrated that patients with memory disorders of varying severity and various etiologies can acquire not only the procedural knowledge needed to perform data-entry operations on a computer but also the factual information associated with the task. Success on the data-entry task was not limited to patients with mild disorders or to those with relatively pure memory deficits. Although patients were quite variable in the speed with which they learned the task, even those with substantial intellectual impairment and those with frontal lobe deficits were able to achieve perfect performance. Further, the results of the transfer tests suggested that the learned procedures were not bound absolutely to the specific training materials but could, under some circumstances, be applied across minor variations in materials.

Information that was acquired in the knowledge acquisition phase of the study seems to be properly characterized as declarative—the kind of knowledge that Squire [27] has claimed cannot easily be acquired by amnesic patients. However, although patients were able to acquire the facts associated with a complex task, their rate of acquisition was not normal. In general, they required many more trials than control subjects to achieve criterial levels of performance and took significantly more time to complete a trial. The fact that the two subject groups did not differ in the number of cues needed on the first trial indicates that they possessed equivalent prior knowledge of the task and were comparable in their abilities to guess the target responses at the start of training.

We had speculated earlier that new knowledge might be acquired by amnesic patients through the use of the same implicit memory system or processes that underlie repetition priming—what Schacter [21] has referred to as a perceptual representation system (PRS) (see also Ref. [28]). In fact, the use of the method of vanishing cues was designed to allow patients to use their preserved implicit abilities to respond to fragment cues. Information acquired through priming, however, has frequently been found to be highly specific, less accessible to changed cues or across modalities (e.g. Refs [15] and [24]). The hyperspecific nature of the acquired knowledge reported in the previous Glisky et al. [12, 13] computer studies is consistent with the notion that the knowledge acquired by patients was acquired as a result of priming. If knowledge in the present study was also acquired through priming, we would expect that it too would be largely inaccessible in altered contexts. This, however, was not the case. Patients seemed able to make good use of the knowledge acquired in the first phase of training to facilitate their performance of the actual data-entry task in the second segment of training. They made only slightly more errors when they began the actual data-entry task than control subjects. Transfer of declarative knowledge to the procedural task was thus almost equivalent in the two groups. Note, however, that transfer in this case was assessed implicitly—by performance on the task—rather than explicitly—by requiring production of a specific response to an altered cue.

In addition, despite the good transfer performance, some of the more severely impaired patients reported little explicit awareness of the learning episodes. Others knew that they had been participating in a training program but were unable to articulate the features of that program. Only the mildest patients were able to recall explicit details of their new learning. Yet all were able to perform the data-entry procedures as if they possessed prior knowledge of the task. To ensure that the data-entry task could not be performed readily without prior declarative knowledge, a normal subject was tested in Part I of the skill acquisition phase without first participating in the knowledge acquisition segment. This subject required 24
letter cues on the initial trial to perform the data-entry procedures, considerably more than the mean of 6.8 cues (range 0–13) needed by patients. Patients were thus clearly making use of their recently-acquired factual knowledge to facilitate their performance of the data-entry task.

In a recent case study, Tulving et al. [29] reported that a severely amnesic patient, K.C., was capable of acquiring and retaining over a 12-month interval new factual information, which transferred across modalities, and was stochastically independent of perceptual priming. Tulving et al. concluded that K.C. was able to acquire the new knowledge by virtue of a partly or wholly intact semantic memory. Tulving et al. further speculated that acquisition of new semantic knowledge might occur at a slower rate in amnesic patients because they could not take advantage of episodic memory to support their performance as normal subjects could.

The patients in the present study may also have acquired new semantic knowledge of a declarative nature. Their learning appeared not to be characterized by the same kind of specificity often associated with priming or procedural learning. Instead, patients seemed able to access the knowledge that they acquired in the first part of the study (the knowledge acquisition phase) to facilitate their performance of the data-entry task in the second phase of the study. Like Tulving et al.'s patient, these patients were slow to acquire the new knowledge. Once they had learned it, however, amnesic patients were able to use it (within the constraints of the experiment) in much the same way as normal subjects.

How can the results of the present study be reconciled with the results of earlier studies that suggested that new information acquired by amnesic patients was hyperspecific? Two explanations are possible. First, in the earlier studies transfer of learning was assessed by asking subjects to produce target responses to altered cues such that explicit retrieval of previously-learned information seemed to be required. Under these circumstances, patients had difficulty accessing the knowledge and transfer was poor. In the present study, transfer was assessed by a performance test, that is, implicitly. Subjects were simply asked to perform the data-entry task: they were not asked to retrieve specific responses. In fact, when specifically asked what they had learned, they were frequently unable to respond except in a general sense. It appears therefore that patients can make use of new semantic learning to facilitate performance even though they are unable to access that knowledge explicitly.

Second, in the earlier vocabulary learning study, patients were given 64 trials to learn 15 items. All of the items were not learned by all patients, and although transfer was only assessed for those items that had been acquired, some of the items may not have been learned very thoroughly. In a recent study [3, 11], we demonstrated that transfer of new declarative information improved with greater degrees of overlearning. In the present study, subjects continued the learning procedure until they had completed two consecutive perfect trials. Information may therefore have been well-learned and capable of supporting good transfer.

In the skill acquisition phase of training, patients appeared to acquire the data-entry procedures in a relatively normal fashion. They made only slightly more errors than normal subjects, and although they were slower performing the task, they improved across trials at approximately the same rate. They also showed a non-significant decrease in speed of performance across the 4-week retention interval as did normal subjects. These findings, then, are consistent with previous demonstrations of normal procedural or skill learning by amnesic patients (e.g. Ref. [19]). Because of different initial levels of speed of performance across groups, however, claims of normal acquisition of procedural knowledge by amnesic patients need to be interpreted cautiously. Also, although patients did not make significantly
more errors than control subjects on the data-entry task, their errors tended to persist for somewhat longer.

Procedural learning has been characterized as domain-specific and rigid, not flexibly accessible [1, 26, 27]. Slowing in the performance of well-learned skills is thus expected in changed contexts. In the present experiment transfer of the data-entry procedures was assessed by changing some of the diagnostic information on the cards as well as the location of relevant information. These changes resulted in non-significant increases in errors for both groups and a slowing of data-entry performance. Patients' performance slowed somewhat more than did that of control subjects. Continued practice with the transfer materials, however, enabled both groups to approach baseline levels of performance by the end of a second trial. Patients thus seemed to respond to the transfer tasks in very much the same way as normal subjects.

In summary, the present experiment has demonstrated that memory-impaired patients with memory disorders of varying severity and of various etiologies can acquire and retain both declarative and procedural knowledge. In addition, they are capable of using newly-acquired factual knowledge to facilitate their learning of a procedural task. Patients' learning of the complex procedural task of computer data-entry appears to proceed normally, given prior acquisition of the necessary facts, and survives transfer across minor variations in materials reasonably well.

From a rehabilitation perspective, these findings suggest that a computer data-entry task is an appropriate candidate for vocational training of amnesic patients, although lengthy training periods may be required. Once information and procedures are well-learned or perhaps overlearned, however, they appear to be quite durable and capable of supporting at least some forms of transfer. Additional research in this area should focus on variables affecting the extent and circumstances of transfer.

From a theoretical point of view, these results suggest that many amnesic patients are capable of acquiring not only procedural knowledge but also new semantic information of a factual nature, although not at a normal rate. Exactly what processes are involved in the acquisition of new semantic memories is not yet clear, nor is the issue of whether semantic memory is completely or partially intact in amnesic patients. Studies investigating variables that may affect the rate of acquisition of semantic learning and the probability of transfer may provide important insights concerning semantic memory in both normal and dysfunctional populations.

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