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COMPUTER LEARNING BY MEMORY-IMPAIRED PATIENTS: ACQUISITION AND RETENTION OF COMPLEX KNOWLEDGE*

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Abstract—Several investigators have shown that memory-impaired patients are capable of learning relatively simple information in both the laboratory and everyday life. The present research explored whether patients with memory disorders could also acquire complex knowledge—the domain-specific knowledge needed for operating and interacting with a microcomputer. The results indicated that patients with memory disorders of varying severity could learn to manipulate information on the computer screen, to write, edit and execute simple computer programs, and to perform disk storage and retrieval operations. The learning process, however, was slow relative to controls and the knowledge acquired appeared to be qualitatively different. Theoretical and practical implications of these findings are discussed.

INTRODUCTION

MEMORY deficits are among the most debilitating consequences of brain injury and disease. They affect many aspects of daily living and can seriously disrupt an individual's ability to function independently. Associated with a variety of neurological conditions, including closed-head injury, Alzheimer's disease, ruptured aneurysm, anoxia, encephalitis, Korsakoff's disease and cerebral tumour, memory disorders are as yet poorly understood and have proven largely resistant to remediation. In recent years, however, it has become increasingly evident that even severely amnesic patients retain the capacity for some kinds of learning (for reviews, see [1, 4, 24, 26]). The demonstration of spared learning abilities in memory-disordered patients raises both theoretical and practical questions. From a theoretical point of view, important questions concern the kinds of learning that are preserved and the processes involved in such learning. From the practical standpoint, questions arise as to whether spared learning abilities can be used to alleviate or bypass some of the problems that confront memory-disordered patients in everyday life and how this objective can be achieved.

With a view towards addressing both the theoretical and practical issues, we have initiated a research program to examine the abilities of memory-disordered patients to acquire and use knowledge and skills that are applicable to problems of daily living. The present paper describes this research. Specifically, the paper provides (a) a description of our general approach, which focuses upon what we call the *acquisition of domain-specific knowledge*; (b) a report of three inter-related studies that demonstrate acquisition, by memory-impaired patients, of the complex knowledge needed for interacting with and programming a

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microcomputer; and (c) a discussion of both the theoretical and practical implications of our findings.

ACQUISITION OF DOMAIN-SPECIFIC KNOWLEDGE

During the past decade, an increasing amount of research has been concerned with remediation of memory disorders (for reviews, see [13, 23, 39]). The implicit and sometimes explicit goal of this research has been to restore memory function, either by using repetitive drills or by teaching mnemonic strategies [27]. Empirical evidence, however, has failed to demonstrate that such training procedures produce any general improvements in memory function. A number of investigators have therefore argued that *restoration of mnemonic function* in patients with organic memory disorders is presently an unrealistic goal [19, 27, 40].

An alternative approach to memory remediation, discussed by SCHACTER and GLISKY [27], focuses on the acquisition of domain-specific knowledge: knowledge pertaining to a particular task or function that is important for patients' everyday lives. The general goal of this approach is to *alleviate specific problems* associated with memory deficits by teaching patients the requisite knowledge or skills. Several lines of research suggest that it may be possible to achieve this goal.

First, a number of studies have shown that memory-impaired patients can learn specific pieces of new information, even when memory function does not show generalized improvement (e.g. [6, 18, 28, 29]).

Second, several reports have indicated that patients with memory deficits can acquire discrete bits of information important to their daily needs, such as the names of people in their immediate environments [8, 9, 15, 37, 38] and some aspects of behaviour appropriate to their home or hospital surroundings [8, 30, 38].

Third, as noted earlier, an impressive body of evidence shows that some kinds of learning abilities are spared in memory-disordered patients. A number of studies have shown that memory-impaired patients of various etiologies, including severely amnesic patients, can acquire perceptual, motor and cognitive skills, such as mirror reading [5, 21], rotary pursuit [20] and puzzle solving [2]. Other studies (e.g. [3, 7, 12, 14, 25, 33–35]) have demonstrated that patients' performance on a number of tasks is facilitated normally by a single prior presentation of a stimulus, a phenomenon known as repetition or direct priming. For example, when memory-disordered patients are given letter-fragment cues (e.g. CHA__) and are asked to write down the first word that comes to mind, they are as likely as normal subjects to produce the recently exposed word CHAIR. This relatively normal performance of memory-disordered patients in skill learning and priming studies indicates that patients have considerable capacity for learning even though they have little or no explicit memory for the occasion of learning.

The results of the foregoing studies suggest that memory-impaired patients can acquire new knowledge within specific domains. However, the knowledge acquired in these studies has been relatively simple and, in many cases, learning has been demonstrated only on laboratory tasks. It is thus not yet known whether memory-impaired patients can acquire the more complex forms of knowledge that are needed to perform essential tasks in everyday life.

In the present article we examine whether patients with memory impairments can use their preserved learning abilities to acquire complex knowledge within a specific knowledge domain. The domain that we have chosen to explore concerns the understanding and operation of a microcomputer. Computer-related knowledge is comprised of an extensive body of inter-related facts, and is therefore well-suited to the study of complex learning (e.g. [22]). At the same time, operating a microcomputer is a potentially useful skill for patients with memory problems. With its capacity to store large amounts of information, a computer could function as a kind of prosthetic device, as an artificial memory capable of producing on demand, information, guidance, instructions, and reminders about all aspects of daily living (e.g. [16, 17, 31]). However, previous attempts to teach patients to use even a simple computing device as an external memory aid have been severely limited by patients' inability to learn basic operating procedures [40]. We reasoned that the potential benefits of a microcomputer for memory-disordered patients would be increased if they could learn to interact independently with it and also learn some basic operating procedures.

In an earlier study, we investigated whether memory-impaired patients could learn the meanings of a small number of computer-related terms [10]. We developed a teaching technique called the *method of vanishing cues* in which patients are initially cued with as many letters of the target words as are needed to elicit the correct response. Letters are then gradually withdrawn across learning trials until eventually the patient must produce the target word in the absence of any letter cues. We found that four patients with different degrees of memory impairment could acquire, and retain across a six-week delay, new computer-related vocabulary. In addition, learning achieved by the method of vanishing cues was more rapid and more flexible than learning attained by a standard repetition procedure. Not surprisingly, patients' rate of learning was slower than that of control subjects. More important, perhaps, was the suggestion in our data that the consequences of learning were qualitatively different for patients and controls. The memory-impaired subjects had greater difficulty producing the vocabulary words to changed cues on a transfer test; and, although they produced the correct responses, they often did not appear to remember learning them. These observations suggested that vocabulary learning may have been mediated by different underlying processes in patient and control subjects, and that the nature of knowledge acquired by the two subject groups was in some way different.

In the present study, we investigated further the nature and limits of the knowledge that can be acquired by patients with memory impairments, and we began to explore how that knowledge is organized and under what conditions patients can gain access to it. Learning to produce a word to an unchanging definition might represent the acquisition of a relatively simple stimulus–response bond. However, learning to use the word as a computer command in multiple situations implies the formation of a more complex knowledge structure. We wanted to determine whether patients could acquire and use knowledge structures that would allow them to perform basic operations on a microcomputer.

To investigate this issue, we developed a series of interactive computer programs that required the user to interact independently with a microcomputer and to perform a variety of computer operations. The training technique that we used involved a variation of our method of vanishing cues [10]. We hypothesized that prompting with partial letter cues would tap learning mechanisms that are intact in memory-impaired patients and thereby permit the acquisition of some forms of new knowledge. We made no predictions about the extent or range of knowledge that patients could acquire in this way. We expected, however, in line with our previous empirical findings, that the learning process would be slow relative to controls and that the knowledge would be qualitatively different and perhaps less flexible than that acquired by controls.

METHODS

A series of three interactive computer programs or 'lessons' were designed to engage individuals in a dynamic dialogue with a microcomputer and to teach them basic computer operations and concepts. The three computer lessons were graded in complexity, with each lesson building upon and extending the concepts learned in the preceding lesson. The general teaching procedure was the same for all three lessons and will be outlined first. Then the unique features of each lesson will be described.

Subjects

Four memory-impaired patients and four control subjects were selected from among those participating in a longitudinal study of organic memory disorders currently being conducted at the Unit for Memory Disorders. The four patients had suffered closed-head injuries in motor vehicle accidents at least two years prior to the experiment, and were selected for the present study because they represented a range of severity of memory impairments. Patient characteristics are summarized in Table 1. Patient C.H. is severely amnesic; he is unable to recall anything beyond a minute or two of its occurrence and he remembers none of his more than 100 visits to the Unit over the last 18 months. However, his IQ is in the normal range, as are his comprehension and naming abilities, as reflected by his normal performance on the Token Test and the Benton Visual Naming Test (Table 1). Patients G.X. and V.G. have memory problems in the mild to moderate range, and like C.H., show relatively intact intellectual function. It is worth noting, however, that V.G.'s memory problems are restricted largely to the verbal domain. Patient G.R. has moderate-to-severe memory deficits and also has some attentional, visuoperceptual and cognitive problems. Patients G.R. and G.X. also have extensive motor slowing. (For this reason, verbal IQ may be a more representative measure of intellectual ability than the full-scale score.) The mean verbal IQ (96.8) of the patient group, as measured on the Wechsler Adult Intelligence Scale-Revised (WAIS-R), is in the averge range. The mean MQ (77.6), obtained from the Wechsler Memory Scale (WMS), is well below the mean IQ, indicating substantial memory deficits. Patients were particularly impaired on delayed tests of logical memory and visual reproduction (WMS sub-tests), recalling virtually nothing of either the stories or the pictures after 30 min. (The mildly-impaired patient V.G. retains some visual information over time but is clearly impaired relative to controls.) In addition, none of the patients was able to recall any of the 'hard' (i.e. unrelated) paired associates after a delay.

The control group consisted of four subjects approximately matched to the patients on the basis of age and verbal IQ (Table 2). Two of the four subjects in the control group had suffered closed-head injuries: B.D., who has no cognitive deficits, and M.M., who has some attentional problems. We included M.M. as a control because one of our memory-impaired patients (G.R.) also has attentional problems. The other two controls were volunteers with no history of neurological impairment. As Table 2 shows, the control subjects' MQs are in all cases higher than their IQs.

All patients and control subjects had previously participated in a computer-vocabulary learning program and had learned the definitions of some computer-related words. (Data concerning two of the patients and three of the

Table 1. Characteristics of memory-impaired subjects

	Patients				
	G.R.	G.X.	C.H.	V.G.	Mean
Diagnosis	CHI	CHI	CHI	CHI	
Years post-trauma	4	5	3	2	
Age	25	22	33	24	26
Education (yr)	15	11	16	13	13.8
WAIS-R	73	86	88	124	92.8
VIQ	82	96	96	113	96.8
WMS	61.5	83.5	79.5	86	77.6
Logical memory					
Immediate	6	9	7	4	6.5
Delayed	2	0	0	1	0.8
Visual reproduction					
Immediate	3	10	10	10	8.3
Delayed	1	1	0	6	2.0
Hard associates					
Immediate (Trial 3)	2	0	0	2	1.0
Delayed	0	0	0	0	0.0
Token test (normal ≥ 29)	34	34.5	34	34	
Benton Visual Naming (normal ≥ 50)	54	54	56	60	

Table 2. Characteristics of control subjects

Subject	Age	Education (yr)	WAIS-R	VIQ	WMS
M.M.	26	12	92	89	96.5
S.B.	37	12	96	99	102
B.D.	31	17	91	95	122
R.B.	47	12	109	100	132
Mean	35.3	13.3	97	95.8	113.1

controls are reported in GLISKY *et. al.* [10].) All participants were also familiar with the computer keyboard and had been instructed in the use of the RETURN key. None of the subjects, however, had ever used a computer as anything other than a typewriter or had any prior knowledge of basic procedures.

General procedure

Patients were seated in front of an Apple II + or IIe microcomputer, and simply told to follow the instructions that appeared on the computer screen in front of them. The computer then instructed them to type their responses to all queries on the keyboard, to guess if they were uncertain of how to respond, and to press the RETURN key for a hint if they were unable to respond at all. Step-by-step instructions concerning a particular computer operation or concept were then displayed on the computer screen. Explanations of concepts entailed a few simple sentences, which were presented one sentence at a time. Rather than simply passively reading these instructions, patients were required to complete some of the sentences by typing appropriate words on the keyboard. They then performed several tasks using the computer command that was being taught. Thus an interaction between computer and patient continued throughout the course of each lesson. Several different kinds of computer/patient interaction were included.

1. Some of the instructions concerning the meaning or use of various computer terms or commands were presented as incomplete sentences, and patients had to generate the missing words. For example, when explaining the procedure for displaying a particular word on the screen, the computer presented the incomplete sentence, "A sequence of characters enclosed in quotation marks is called a ____." Patients were required to type the word STRING to complete this sentence correctly. The next sentence then read, "If you want the computer to display a particular string on the screen, you tell it to ____." This sentence could be correctly completed by typing the computer command, PRINT. If patients did not know what to type, they could ask for a hint by pressing the RETURN key on the computer keyboard. The initial letter of the target word then appeared on the screen. Additional cues in the form of successive target letters could be requested if necessary, and after each letter addition an opportunity was provided for the patient to type the correct word on the keyboard. Incorrect responses always resulted in the provision of an additional letter. The purpose of this type of computer/patient interaction was three-fold: to teach memory-impaired patients the meaning and use of some new computer terms; to extend or elaborate the meanings of computer terminology learned previously; and to ensure that patients were actively involved in processing the instructions for the new concepts that they were learning.

2. After a concept or operation was explained, patients were asked to demonstrate their knowledge and understanding of the concept by typing appropriate commands on the computer keyboard. For example, after working through the instructions outlined in paragraph 1 above, patients were directed to "Ask the computer to display the word HELLO on the screen". To fulfill this task, they had to type the phrase, PRINT "HELLO". That is, they had to use the appropriate command PRINT followed by the desired string, in this case the word HELLO, which had to be enclosed in quotation marks. When they typed the command correctly, the computer executed the instruction: the word HELLO appeared on the computer screen. If they typed the command incorrectly, the computer responded in a manner appropriate to the type of error that had been made. In most cases, a simple message appeared immediately on the screen informing the subjects that their response was incorrect and that a hint would be provided. Hints were usually the first letter or character of the correct response, followed by additional letters as needed. In instances where letter fragments were not appropriate cues, more direct prompts were given, and in some cases patients were guided towards discovery of their own errors. Examples of these other prompts will be provided in the more detailed description of each lesson. A continuing interaction between patient and computer was thus achieved. This interaction entailed not only responses by patients to the computer's instructions but also responses by the computer to instructions issued by the patients. The computer's responses, furthermore, were contingent upon and appropriate to the form and content of the patients' responses. Only the correct command produced the desired outcome. Incorrect commands yielded inappropriate outcomes, the nature of which was dependent on the particular command and on the type of error.

3. A third type of computer/patient interaction occurred after the computer attempted to execute a command that a patient had given. Where appropriate, patients were queried as to whether or not the command was carried

out correctly. For example, patients might be asked, "Did the computer do what you asked it to do?" They were thus required to evaluate what had happened and make a positive or negative response (i.e. type "yes" or "no"). If the response was negative, the computer would then lead subjects through a series of steps aimed at identifying and correcting the error. If no error was made, the program would simply continue to its next instruction.

Because of the contingent nature of the computer/patient interaction, the number of stimuli presented and the number of responses made varied somewhat from subject to subject and from trial to trial. All participants, however, were instructed in the same concepts in the same order and were required to make a specified minimum number of responses. Beyond that minimum, the number of responses was dependent on the number of errors. For example, whenever subjects made programming errors they had to display their programs on the screen in order to correct them. Subjects who made more errors were therefore required to use the display command, LIST, more times than subjects who made fewer errors.

Subjects worked on the three computer lessons independently and at their own pace. Performance was assessed in terms of the numbers of hints that were needed to complete the lesson correctly. At the end of each trial, the computer displayed the number of hints required, printed a qualitative comment on the level of performance such as "Not bad" or "Very good", and encouraged the use of fewer hints on the next trial. When performance on a lesson was perfect or appeared to have reached an asymptote at a near-perfect level, subjects moved on to the next lesson. Different subjects therefore received different numbers of trials on each lesson. Note also that although 'best' performance is represented by zero hints, there is no meaningful measure of 'worst' performance, because the possibilities for error are essentially limitless.

From time to time during the training, subjects were moved to a different testing room and were questioned verbally about the concepts that they had been learning. Responses to these questions provided qualitative information about the nature of the acquired knowledge and presented an additional basis for comparison between memory-disordered patients and control subjects.

Subjects came to the laboratory twice a week and stayed for approximately two hours each session. They completed as many trials as possible within the two-hour time frame. In general, fewer trials were completed during the early sessions of each lesson when performance was less skilled, than during the later sessions.

Lesson 1

Lesson 1 was concerned with the teaching of two computer operations: (a) the display of literal information on the computer screen, using the PRINT command, and (b) the erasing of information from the computer screen, using the HOME command. The PRINT command, which is used to display information on the screen, requires the typing of the word PRINT followed by a sequence of characters enclosed in quotation marks (e.g. PRINT "SOMETHING"). When this command is input correctly, the string SOMETHING is reproduced on the computer screen. The instructions for the PRINT command included three sentences to be completed with the words BASIC, STRING and PRINT. The first two words were part of the earlier vocabulary study; the sentences for those words extended or elaborated the previously-learned meanings. The word PRINT was new. After processing the instructions, subjects were required to use the PRINT command on five different occasions to instruct the computer to display a variety of strings on the screen. In each case, correct use of the command resulted in the display of the appropriate string. Subjects also learned to type the word HOME in order to clear information from the screen. They used this command four times. Thus a minimum of 12 operations comprised the patient's response repertory in Lesson 1: three sentence completions, five PRINT commands and four HOME commands. Table 3 summarizes the different kinds of operations required in Lesson 1 and in the subsequent lessons and indicates the minimum numbers of times each response was required.

With one exception, errors and omissions resulted in the provision of initial-letter (or character) cues followed by additional letters as needed. Each letter that was provided counted as one hint. The only other kind of prompt that was included in Lesson 1 occurred if patients typed the command PRINT without an accompanying string or with an incorrect form of the string. In this case, the query PRINT WHAT? (counting as one hint) appeared on the screen giving patients a single opportunity to detect their error and correct it. If they were unable to correct their mistake, the first character of the string (i.e. the opening quotation mark, ") was then provided, followed by successive letters as required.

Lesson 2

Lesson 2 introduced the concept of a program. "Program" was defined as a set of instructions to be carried out by the computer at a later time. Patients were informed that all instructions in a program had to be preceded by line numbers, which determined the order in which the instructions were executed. They were then required to write a simple program incorporating the commands learned in Lesson 1 (e.g., 10 PRINT "HELLO"). A three-line program was constructed, one line at a time (see Table 3). In the course of writing the program, extensive use was made of the LIST (to display the program on the screen) and RUN (to execute the instructions in a program) commands; each was used a minimum of four times and in most cases several more times, particularly in the first few trials where program errors were most likely. Use of the HOME command to clear the screen was also necessary on at least six different occasions.

Disk storage operations were also introduced in Lesson 2. Patients were instructed that programs were stored

Table 3. Computer concepts and commands in Lessons 1–3: minimum numbers of operations required

	Definitional sentence completions		Commands used		Program lines (each used once)
Lesson 1	BASIC–	1	PRINT "???"–	5	
(12)*	STRING–	1	HOME–	4	
	PRINT	1			
Lesson 2	STRING–	1	PRINT "???"–	1	10 PRINT "HELLO"
(29)*	PRINT–	1	HOME–	6	20 PRINT "GEORGE"
	PROGRAM–	1	LIST–	4	30 PRINT "MAY 30 1985"
	(LINE) NUMBER–	2	RUN–	4	
	RUN–	1	SAVE NAME–	1	
	LIST–	1	LOCK NAME–	1	
			CATALOG–	2	
Lesson 3	REMARK–	1	LOAD NAME–	2	25 PRINT "ELIZABETH"
(73)*	CLEARS THE SCREEN–	1	HOME–	12	35 PRINT "GLISKY"
	STRING–	1	LIST–	19	25
	EDITING–	1	RUN–	8	25 PRINT "ELIZABETH"
			SAVE NAME–	4	40 PRINT "LOUISE"
			LOCK NAME–	4	30 PRINT "LOUISE"
			CATALOG–	10	40
			NEW–	2	50 PRINT "WAS HERE"

*Total minimum number of operations.

according to names created by the programmer. They then stored their programs on the disk by using the SAVE command (i.e. SAVE NAME), protected their stored programs by typing the LOCK command, and checked the contents of the disk with the CATALOG command.

As can be seen from Table 3, Lesson 2 required the following operations: six sentence completions, two of which were repeated from Lesson 1 and four of which were new; seven different computer commands of which five were new; and three unique program lines. Several commands were repeated more than once so that the total number of operations required was 29. Lesson 2 was thus considerably more complex than Lesson 1, both in terms of the number of new concepts and commands introduced and in terms of the total numbers of responses required.

As in Lesson 1, most errors and omissions were immediately followed by the provision of letter-fragment cues, but more direct prompts were also used where appropriate. For example, when patients failed to put a line number at the beginning of each program line, a corrective message appeared on the screen: REMEMBER TO TYPE THE LINE NUMBER. Failure to include the program name following the SAVE or LOCK command resulted in the query SAVE (or LOCK) WHAT? Errors made in program writing, however, were not immediately corrected. They had to be detected by the patients themselves when the program failed to run properly. When the error was identified, patients were guided through appropriate correction procedures. For example, when a patient attempted to RUN the incorrect program, 10 PRINT GEORGE (GEORGE should be in quotation marks), a zero was displayed on the screen instead of the name GEORGE. When the patient was then questioned, "Did the program do what you wanted it to do?", a "no" reply cued the error-detection procedures. Patients were then required to display their programs on the screen (LIST), to examine Line 10 for an error, and to respond to error-probing questions such as, "Did you forget the quotation marks?" When the particular error was detected, the patient re-typed the line correctly and tried running the program again. Patients tested their programs after adding each program line, and proceeded through an error-detection routine whenever they made a mistake. A partial protocol of one patient's interaction with the computer during Lesson 2 is presented in Table 4.

Lesson 3

Lesson 3 entailed more program writing, introduced several program editing techniques, and required extensive use of disk storage operations. In addition, the LOAD command was introduced for the first time as a means of retrieving information from the disk and transferring it into the computer's memory. Patients were required to LOAD an existing three-line program from the disk (i.e. LOAD NAME) and then to specify the function of each program line. They had to identify a REMARK, a STRING, and the screen-clearing command, HOME. They were then required to change or "edit" the program in a number of different ways: (a) by over-writing a program line; (b) by adding new program lines; (c) by deleting existing program lines (i.e. type a line number and then press RETURN); and (d) by changing the order of command execution through manipulation of line numbers. They also learned how to delete entire programs from the computer's memory through the use of the NEW command. Using these editing techniques, patients wrote a minimum of four simple programs, each of which displayed one or more strings on the screen.

Table 4. Sample protocol of computer (C)/patient (P) interaction during portions of Lesson 2

C:	WRITE A PROGRAM THAT DISPLAYS THE WORD HELLO ON THE SCREEN
P:	PRINT HELLO
C:	REMEMBER TO TYPE THE LINE NUMBER
P:	20 PRINT HELLO
C:	TRY RUNNING YOUR PROGRAM
P:	[Presses RETURN for a hint]
C:	R
P:	RUN
C:	[Program fails to run] YOU HAVE MADE AN ERROR. DISPLAY YOUR PROGRAM ON THE SCREEN
P:	[Presses RETURN for a hint]
C:	L
P:	LOAD
C:	INCORRECT. HERE'S A HINT LI
P:	LIST
C:	[Program appears on screen] 20 PRINT HELLO DID YOU FORGET THE QUOTATION MARKS?
P:	YES
C:	TYPE THE LINE OVER AGAIN CORRECTLY
P:	20 PRINT "HELLO"
	[Patient then writes and edits a three-line program]
C:	DISPLAY YOUR PROGRAM ON THE SCREEN
P:	LIST
C:	[Program appears on screen] 20 PRINT "HELLO" 25 PRINT "GEORGE" 30 PRINT "FEBRUARY 2, 1985" TRY RUNNING YOUR PROGRAM
P:	RUN
C:	[Program commands are executed] HELLO GEORGE FEBRUARY 2, 1985 NOW STORE THE PROGRAM ON THE DISK
P:	SAVE
C:	SAVE WHAT?
P:	SAVE NAME
C:	[Program is saved on the disk] LOOK AT THE CONTENTS OF THE DISK TO SEE IF YOUR PROGRAM HAS BEEN STORED
P:	LIST
C:	INCORRECT. HERE'S A HINT C
P:	CATALOG
C:	[File names on disk appear on screen] NOW PROTECT YOUR PROGRAM SO THAT IT CANNOT BE ACCIDENTALLY ERASED
P:	LOCK NAME
C:	CLEAR THE SCREEN
P:	HOME
C:	[Screen goes blank]

As in the previous lesson, program development was achieved gradually through a continuing dialogue between patient and computer during which programs were displayed (LIST), tested (RUN), corrected, evaluated, stored (SAVE NAME) and protected (LOCK NAME). Although only two new computer commands were introduced in this lesson (LOAD and NEW), other features contributed to its complexity: (a) all learning from the prior two lessons was incorporated into Lesson 3 and was integrated with the new concepts; (b) commands had to be used in several contexts; and (c) the dialogue was lengthy. Mastery of Lesson 3 entailed a minimum of 73 separate operations on the keyboard, including four definitional sentence completions, eight unique program lines, and eight different computer commands repeated varied numbers of times (see Table 3).

When the three lessons had been successfully completed, subjects were trained on a rather different aspect of computer operation: mathematical problem solving. (Data from the mathematical programs will not be reported in this paper.) There then followed an interval of at least one month during which all subjects, with the exception of patient C.H., had no exposure to a microcomputer. Subjects then returned to the laboratory and were re-tested on Lessons 2 and 3. Because C.H. had considerable difficulty with the mathematical training program, he continued working on that program during the retention interval. There is, however, little overlap between the concepts and commands in the mathematical lessons and those that comprised the earlier lessons; only the HOME command is used in all lessons. The PRINT command is required in the mathematical program but has a different meaning and different syntax than in Lessons 1–3. One control subject, B.D., was unavailable for re-testing.

RESULTS

The results obtained in each of the three lessons include both quantitative measures of learning and retention, and qualitative observations concerning the nature of the acquired knowledge. In general, the data indicated that the patients were able to acquire and retain the knowledge necessary to perform a variety of computer functions. However, their rate of learning was considerably slower and their acquired knowledge appeared to be qualitatively different from that of control subjects.

Quantitative measures of learning and retention

Initial performance measures for patients and controls on each lesson are shown in Table 5. Because of the reiterative nature of each lesson in which the same concepts and commands are used repeatedly, the total number of hints required to complete the first trial of each lesson reflects not only prior knowledge and comprehension abilities but also within-trial learning and memory. Accordingly, initial learning was assessed by totalling the number of hints required to produce or use correctly each word or concept the first time it occurred in a lesson. As can be seen in the left half of Table 5, there was little difference between patients and controls in numbers of hints needed to produce the correct words on their first occurrence. This finding confirms that the two groups were approximately equivalent in relevant knowledge and abilities prior to the start of the training programs for each lesson. However, by the end of the first trial of each lesson, control subjects showed a clear performance advantage over patients (right half of Table 5). They made many fewer errors on repeated items and thus required far fewer hints to complete the first trial correctly.

Table 5. Initial performance by patients and controls on Lessons 1–3: number of hints required on the first occurrence of an item and total number of hints required to complete the first trial

	First occurrence Lesson			First trial Lesson		
	1	2	3	1	2	3
Patients						
V.G.	5	12	3	11	15	10
G.X.	4	24	26	13	54	42
G.R.	11	23	26	34	54	56
C.H.	13	40	24	36	83	70
Mean	8.3	24.8	19.8	23.5	51.5	44.5
Controls						
R.B.	8	16	20	12	17	26
S.B.	6	40	12	10	42	20
M.M.	13	45	19	23	73	29
B.D.	6	10	8	6	12	9
Mean	8.3	27.8	14.8	12.8	36	21

There were also only small differences between memory-impaired and control subjects on final levels of performance achieved on each of the three lessons (Table 6). In comparison with their initial levels of performance, all patients showed great improvement and, by the end of training, they needed very few hints for correct performance on all lessons with one notable exception. Patient G.R. had persistent difficulties with Lesson 3, which were probably attributable to attentional problems arising from the length of the program. Even so, her final

Table 6. Performance of patients and controls on Lessons 1–3: number of hints required on final learning trials, long-term retention scores, and number of learning trials

	Final score Lesson			Long-term retention* Lesson		Number of trials Lesson		
	1	2	3	2	3	1	2	3
Patients								
V.G.	0	0	0	3	3	5	14	7
G.X.	0	2	2	7	6	4	32	22
G.R.	2	2	10	7	10	20	54	39
C.H.	3	2	5	4	9	45	55	54
Mean	1.3	1.5	4.3	5.3	7.0	18.5	38.8	30.5
Controls								
R.B.	1	1	0	10	0	2	5	4
S.B.	0	0	2	6	3	3	6	9
M.M.	0	2	0	2	6	3	15	10
B.D.	0	0	0	—	—	2	4	4
Mean	0.3	0.8	0.5	6.0	3.0	2.5	7.5	6.8

*Retention interval for V.G. = 3 months, for G.R. = 2 months; for all other subjects = 1 month.

score of 10 hints represented a substantial improvement relative to her first-trial score of 56 hints.

Patients also retained what they had learned across a retention interval of at least one month. The middle columns of Table 6, which show the number of hints required on delayed tests of Lessons 2 and 3, indicate that there was little forgetting over time by either memory-impaired or control subjects. In fact, two of the patients, G.R. and V.G., still retained most of what they had learned after two and three months respectively.

Although all four patients showed consistent learning and substantial retention, performance was far from normal. As can be seen from the right-most columns of Table 6, subjects with memory disorders required many more trials to achieve criterial levels of performance than did controls. Although patients learned to carry out the various operations and eventually made few errors, it took them days of practice and many repetitions to attain their final level of performance.

The pattern of learning exhibited by each of the memory-disordered patients is illustrated in Fig. 1, which depicts session-by-session learning performance on Lesson 2. The numbers of hints required at the beginning and end of each session are shown. Note the substantial reduction in the number of hints needed across the trials of the first session for patients C.H. and G.X. In fact, both patients made close to 50% fewer errors on the second trial than they did on the first. Patients V.G. and G.R. showed a similar marked improvment in performance but it occurred in the second and third sessions respectively. Within-session learning, however, was almost always followed by considerable between-session forgetting, although across learning sessions the mean number of errors per session steadily declined. The learning advantages for control subjects were evident in both greater within-session learning and less between-session forgetting. Controls were also less variable in their performance than were patients and rarely regressed within a session as patients sometimes did.

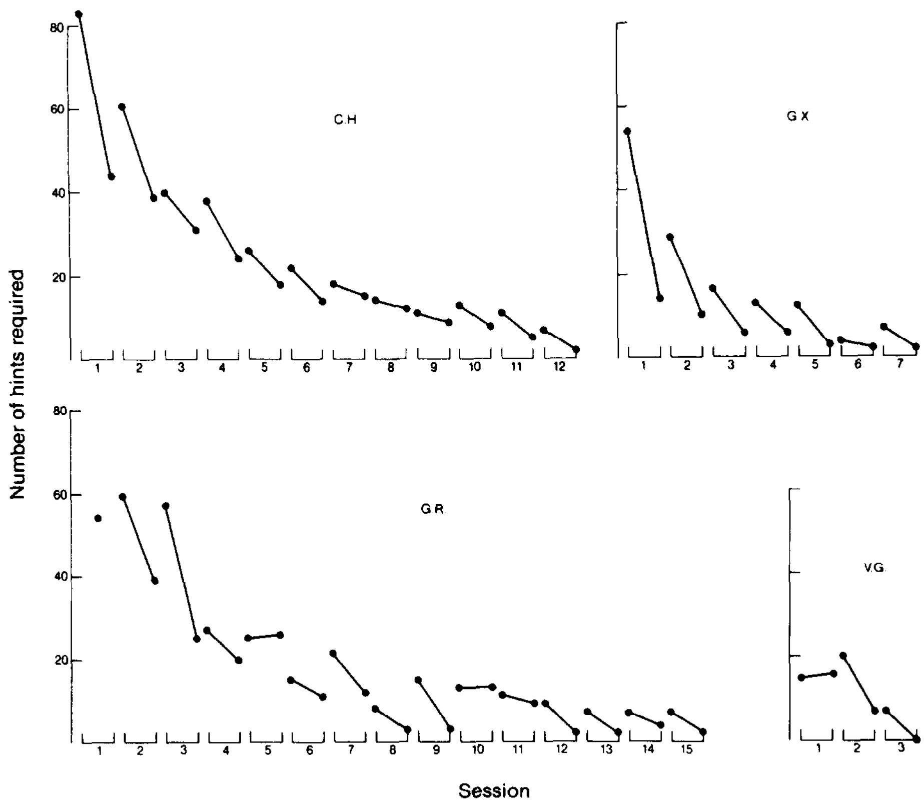

FIG. 1. Number of hints required by each of four memory-impaired patients on Lesson 2. Points represent performance on the first and last trials of each session. Sessions were conducted twice weekly.

Qualitative observations

The quality of knowledge acquired by the subjects was evaluated in two ways. First, at a time when patients' and controls' quantitative performance levels were approximately equal—after the final learning session on Lesson 3—we compared the answers that subjects gave to the questions about the computer concepts they had acquired. There were notable differences between the two groups. Patients had difficulty answering general or open-ended questions or questions in which the wording differed from that experienced during training. For example, if asked the question that had been part of the program, "What goes before each instruction in a program?", patients responded correctly, "a number". However, when asked the more general question, "How do you write a program?", three of the four patients failed to mention that a number was needed at the beginning of each line; only the mildly-impaired patient V.G. was able to outline correctly the steps involved in writing a simple program. Also, when patients were asked, "After your program is stored on a disk, how would you make sure that it was not changed, over-written or deleted?", only patient G.X. responded correctly with the LOCK command. However, when asked how to "Protect a program so that it cannot be accidentally erased" (the exact wording from the training sessions), patients replied correctly that they would LOCK it.

Control subjects had no particular problems with general questions and were not affected adversely by slight alterations of wording. They all specified correctly the procedures involved in writing a program, and none of them had any special difficulty producing the LOCK response or any other responses when the wording of a question was changed.

A second way in which we attempted to assess quality of knowledge was by requiring subjects to use what they had learned on a 'transfer' task that presented them with relatively unconstrained conditions. Subjects were asked to write a new program to display the answers to four simple mathematical problems, addition, subtraction, multiplication and division, using the numbers 8 and 2. As noted in the method section, all subjects had previously learned, in a separate lesson, how to perform mathematical operations on a computer (e.g. PRINT 8 + 2) and could do so without error. However, they had never been asked to put this learning into program form, which required that line numbers be placed in front of the commands (i.e. 20 PRINT 8 + 2). Further, performance was not controlled in any special way by the computer; there was no master program that directed or sequenced subjects' responses and no hints were provided.

None of the patients was able to perform this task. In fact, on this transfer task, performance was seriously disrupted. All patients failed to use line numbers and were unable to detect this omission. Only when verbally cued with the exact wording from the earlier training sessions (i.e. "What goes before each instruction in a program?") did patients insert numbers before the commands. Moreover, after generating line numbers some patients then forgot the PRINT command and others committed syntactic errors unlike any that they had made during training. Patients seemed unable to integrate the component parts of the task and all of them required almost an hour of prompting before they completed the simple four-line program.

Control subjects had no such difficulties. Three of the four controls wrote the program correctly without assistance in less than 5 min. Subject S.B. initially omitted the line numbers but was able to generate them when asked to review the steps involved in program writing. She needed 22 min to complete the task.

DISCUSSION

Patients with memory disorders of varying severity can acquire and retain forms of complex knowledge necessary for the operation of a microcomputer. Even a densely amnesic patient such as C.H., who remembers none of his experiences with a computer, can nevertheless learn to write and edit simple programs and to perform several disk storage and retrieval operations. Although memory-impaired patients in the present study were able to attain final performance levels that were quantitatively equivalent to those of controls, the learning achieved was not normal. Many repetitions were required before error-free performance was attained, and the knowledge acquired by patients appeared to differ qualitatively from that acquired by controls.

We have reported results only for four head-injured patients; however, we believe our approach may have general application and can be used with patients of other etiologies. For example, we have also trained a patient whose memory deficit resulted from viral encephalitis. This particular patient, although severely impaired on all standard tests of verbal and non-verbal memory, performs extremely well in learning situations in which materials are presented by means of the vanishing cues procedure. Despite a full-scale IQ of only 82 and MQ of 61, this patient was able to learn and use all of the computer concepts introduced in the computer learning programs. Further, she required fewer trials for learning than any of the closed-head injury patients except the mildly impaired V.G. and she retained what she had learned with very little forgetting over a period of seven months.

The results of the present research extend our previous findings regarding the efficacy of the vanishing cues procedure for memory-impaired patients. Whereas the earlier results indicated that the method of vanishing cues facilitates the acquisition of computer-related vocabulary [10], the present data indicate that the technique can also serve the acquisition of more complex knowledge. We do not as yet understand the nature of the learning processes that are responsible for patients' performance. One possibility is that patients' performance was mediated by damaged or degraded learning mechanisms, and therefore was impaired with respect to controls. Although we cannot rule out this possibility, it is also plausible and heuristically useful to suggest that patients' preserved learning abilities played an important role in their performance. The vanishing cues procedure was designed specifically to tap patients' preserved abilities to produce recently-presented words in the presence of fragment cues, as shown in research on direct priming [3, 7, 11, 12, 25, 34, 35]. Perhaps the repeated presentation of partial letter cues engages preserved learning capacities that ultimately can support the acquisition and retention of knowledge that is necessary to program and interact with the microcomputer.

This kind of knowledge—knowledge of computer commands and operations—appears to be tied closely to action sequences; most of the to-be-learned task elements represent operational procedures that are carried out in a relatively invariant sequence. In this respect, computer learning resembles other kinds of skill acquisition that seem to be spared in memory-disordered patients and that also require the learning of a set of ordered procedures [2, 5, 20]. However, it would probably be incorrect to label the knowledge acquired by patients as entirely 'procedural' (cf. [4, 32]). Although there are procedural components to the tasks, patients' expression of their acquired knowledge did not depend upon actual performance of the computer operations: patients could answer questions about some of the concepts that they had learned, but access to that knowledge occurred only under a narrow range of conditions. Note also that patients' performance in the present study did not proceed in a normal manner as it often does in studies of skill acquistion (e.g. [5, 21]). This observation suggests that normal subjects may have used different and perhaps more efficient processes to learn the programming task, processes that are damaged in memory-disordered patients.

We have referred to the knowledge that is acquired by subjects in the present study as 'complex'. However, as we have implied in the foregoing discussion, the knowledge structures acquired by memory-impaired subjects may be qualitatively different from those acquired by controls. Patients' knowledge can be characterized as 'hyperspecific' (cf. [26]): it is relatively inflexible, rigidly organized, and only narrowly accessible. Patients, particularly those with the most severe memory impairments, were highly dependent on the precise wording of instructions for accurate performance; even the slightest changes sometimes resulted in errors. In addition, they were unable to respond to open-ended or general questions about what they knew, although they could answer specific questions that were worded identically with the instructions they had encountered in the training programs. Patients' behaviour was also disrupted when asked to write a new program without computer guidance or control. They seemed to be relying on the presence of a particular stimulus to trigger the appropriate chain of responses.

A speculative interpretation of these qualitative observations is that patients' knowledge may be organized sequentially or horizontally (cf. [36]) in a stimulus–response fashion. Normal subjects, by contrast, may be able to create vertical or map-like structures in which each of the elements of the structure possess multiple connections to other elements. If this were the case, there would likely be considerable limitations on the complexity of knowledge that patients could acquire and also on the number of points of access to that knowledge. Although these notions are, of course, merely suggestive hypotheses, they merit systematic investigation in future studies of complex learning in memory-disordered patients.

Let us consider next some of the practical implications of the experiment. Our results indicate that patients with a range of memory impairments can learn to interact independently with a microcomputer. They can follow simple instructions and can carry out basic operations without assistance; they can gain access to stored information; they can erase data from the screen in preparation for new displays; and they can store information that they themselves typed at the keyboard. Other investigators have reported that lack of these basic skills has limited the usefulness of electronic devices as external aids for memory-impaired patients [40]. Our demonstration that such skills can be acquired provides some reason for cautious optimism about the possibilities for patients to use a computer as a substitute memory.*

There are, however, several problems yet to be resolved. We do not know whether the computer knowledge acquired by patients in the laboratory can be applied in real-world contexts; the apparent inflexibility of the acquired knowledge could seriously limit the range of situations to which new learning could be applied. With respect to computer operation, precise wording of instructions may be necessary before any commands could be properly executed. In addition, patients may be unable to initiate actions independently and may require a highly structured environment in which to operate. These issues will have to be addressed experimentally before applications to everyday life can be implemented.

Our data may also have more general implications for attempts to teach memory-impaired patients complex knowledge in other domains that are pertinent to everyday life. On the one hand, the previously discussed restrictions on patients' expression of their acquired knowledge represent difficulties that are likely to be encountered by investigators who attempt to teach patients complex knowledge in, for example, occupational or educational domains. Although we have no ready solutions to this problem, we think it is important to be alert to its existence. On the other hand, the results indicate that with use of an effective technique and extensive repetition, even severely impaired patients can acquire a good deal of new knowledge, perhaps more than would have been expected on the basis of previous research. It is worth noting in this regard that the vanishing cues technique makes the learning process quite enjoyable for patients. They do not suffer the frustration often encountered when traditional learning methods are used and are therefore eager to continue with training. These observations suggest that we now possess some of the tools that are necessary for exploring the acquisition of complex knowledge in memory-impaired patients. It remains to be determined to what extent these tools will enable us to design interventions that have a positive impact on patients' day-to-day lives.

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*We wish to emphasize that our endorsement of the microcomputer as a potentially useful prosthetic device does not extend to its use as a means of restoring memory function, either by repetitive drills or by teaching strategies. As we have argued elsewhere, in spite of the current trend towards using computers to restore memory function, there is no evidence that computers have any beneficial effects when used in this way [27].

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