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NOTE

LONG-TERM RETENTION OF COMPUTER LEARNING BY PATIENTS WITH MEMORY DISORDERS*

ELIZABETH L. GLISKY and DANIEL L. SCHACTER†

Department of Psychology, University of Toronto, Ontario, Canada M5S 1A1

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Abstract—Previous research has demonstrated that patients with memory disorders resulting from closed-head injury can acquire the complex knowledge and skills necessary for the use of a microcomputer. The present paper extends the generality of those findings by showing that (1) amnesic patients with other etiologies could similarly learn how to operate a computer and (2) the knowledge and skills acquired were retained over intervals of up to 9 months.

INTRODUCTION

IT IS NOW well established that patients with serious memory disorders have some preserved learning abilities. Despite their difficulties remembering recent experiences and new information, amnesic patients can learn some perceptual, motor, and cognitive skills [1, 4, 11–13] and show robust repetition priming effects on a variety of tests [2, 9, 10, 15, 18, 21, 22]. These demonstrations of preserved learning in amnesic patients have important implications for theories of normal and abnormal memory (e.g. [3, 16, 17, 19, 22]) and possibly significant practical implications as well. SCHACTER and GLISKY [15] suggested that patients' preserved learning abilities might provide a basis for teaching them domain-specific knowledge and skills that could have a positive impact on their everyday lives.

In two recent studies, GLISKY *et al.* [7, 8] reported that a teaching technique designed to tap patients' preserved learning abilities, called the *method of vanishing cues*, helped several memory-disordered patients to acquire complex knowledge needed to operate and interact with a microcomputer. The method of vanishing cues was constructed to make use of amnesic patients' spared ability to produce previously studied words in response to letter fragment cues [9, 21]. For example, to teach patients computer vocabulary, GLISKY *et al.* [8] provided patients with as many letters of a target response as they needed in order to identify it correctly. Letters were then gradually withdrawn from the fragment cue across learning trials until the subject produced the word in the absence of letter cues. Using this technique, we found that four memory-impaired patients were able to learn new computer-related terminology and retain it over a 6-week retention interval.

In a second study [7], we demonstrated that four patients with memory disorders resulting from closed head injury (CHI) could learn to perform basic operations on the microcomputer. Using the vanishing cues procedure, these patients were able to acquire fairly complex new knowledge: they learned to display messages on the screen, clear the screen, store and retrieve information from a disk, and write and edit simple computer programs. They also showed retention of their learning across a 1-month delay.

The present article examines further two aspects of the acquisition of complex computer knowledge in memory-disordered patients. First, in order to evaluate the generality of our previous results, we investigated whether the successful computer learning that we observed in CHI patients is also found in patients with memory disorders of other etiologies. Second, we explored further the retention of complex knowledge over long delays. To accomplish

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†Requests for reprints should be addressed to Elizabeth L. Glisky or Daniel L. Schacter, now at Department of Psychology, University of Arizona, Tucson, AZ 85721, U.S.A.

these objectives, we tested four patients with memory disorders attributable to hypoxia, ruptured aneurysm, temporal lobe abscess, and encephalitis in the computer learning paradigm described by GLISKY *et al.* [7], and examined their performance after retention intervals of 7–9 months. In addition, we retested, at the same long retention interval, the four CHI patients described in our previous report.

METHODS

Subjects

Eight memory-disordered patients, including the four CHI patients from the earlier study and four new patients who had suffered other kinds of brain insult, participated in the present study. Their neuropsychological profiles are summarized in Table 1. The mean IQ (96.8) of the patient group as measured on the WAIS-R is in the average range and is 18 points above the mean MQ (78.4) obtained from the Wechsler Memory Scale (WMS). This differential is indicative of substantial memory deficits. Patients were particularly impaired on WMS subtests of logical memory, visual reproduction, and "hard" paired associates, especially when these tests were delayed by 30 min.

Table 1. Characteristics of memory-impaired patients and control subjects

Patients	Diag.	Age	Educ. (yrs)	WAIS-R	WMS	Log. Mem. Imm	Log. Mem. Del	Vis. Repro. Imm	Vis. Repro. Del	Hard Assoc. Imm	Hard Assoc. Del	Pic. Recog. Hit-FA
V.G.	CHI	24	13	124	86	4	1	10	6	2	0	9
G.X.	CHI	22	11	86	83.5	9	0	10	1	0	0	12
G.R.	CHI	25	15	73	61.5	6	2	3	1	2	0	8
C.H.	CHI	33	16	88	79.5	7	0	10	0	0	0	0
H.D.	Enceph	31	12	84	65	5	0	4	0	0	0	0
W.K.	Hypoxia	49	20	112	89	5	3	8	1	1	1	11
B.B.	Temp lobe abscess	47	15	100	84	6	3	7	4	1	1	15
B.Z.	Aneurysm	38	16	107	79	5	0	7	1	0	0	0
Mean		33.6	14.8	96.8	78.4	5.9	1.1	7.4	1.8	0.8	0.3	6.9
Controls												
R.B.		47	12	109	132	11	7.5	11	9	4	4	15
S.B.		37	12	96	102	8.5	9	10	12	4	3	14
M.M.	CHI	26	12	92	96.5	11	9.5	12	10	3	1	11
B.D.	CHI	31	17	91	122	15	11	12	11	4	4	11
S.J.	CHI	23	15	87	106	10	6	12	11	4	4	14
G.M.		21	15	126	126	13	12	14	13	4	4	—
Mean		30.8	13.8	100.2	114.1	11.4	9	11.8	11	3.8	3.3	13

Detailed individual descriptions of the four CHI patients were reported in an earlier paper [7]. Their memory deficits range in severity from extremely amensic in the case of C.H., who exhibits no delayed recall or recognition of recent experiences, to relatively mild in the case of G.X. Of the four new patients, W.K. and B.B. have memory deficits that are classified as moderate. H.D. and B.Z., however, have severe memory impairments. Like C.H., who is the most severely impaired of the CHI patients, they performed extremely poorly on the delayed WMS tests and on a delayed test of recognition memory for complex scenes. H.D. also has a somewhat depressed IQ and a slight dysnomia as indicated by some problems on the Benton Visual Naming Test. The other three patients show no evidence of intellectual or cognitive impairments with the exception of their memory deficits.

Six control subjects also participated in the study. Three of the six (B.D., M.M. and S.J.) had suffered closed-head injuries but have no measurable memory deficits. M.M. has some attentional problems but was included as a control for patient G.R. who also has attentional difficulties. The control group did not differ from the patient group in age, years of education, or IQ (all $ts < 1$). However, control subjects scored significantly ($P < 0.01$) higher than patients on the overall WMS and on all of the WMS subtests indicated in Table 1.

Procedure

Because the procedure is rather lengthy and was outlined in considerable detail in an earlier paper [7], we will present here only a general description of the methodology. A series of three increasingly-complex computer training programs was constructed to teach patients some of the basic concepts and procedures involved in the use of an Apple IIe microcomputer. Subjects worked on the computer independently and at their own pace. They were required to learn (a) definitions of computer terminology, (b) the use of computer commands to perform screen functions and disk storage and retrieval operations, and (c) the writing and editing of simple programs. Table 2 presents a list of the concepts and commands included in Lessons 2 and 3.

Concepts were explained through the use of definitional sentence completions such as, *A set of instructions to be carried out later is called a* ———. If the patient was unable to complete the sentence correctly, cues in the form of successive letters of the target word were provided until the correct response was given (e.g., P———, PR———, PRO———, "PROGRAM").

Table 2. Computer concepts and commands in Lessons 2 and 3: minimum numbers of operations required

Definitional sentence completions		Commands used		Program lines (each used once)
Lesson 2 (29)*				
STRING–	1	PRINT "???"–	1	10 PRINT "HELLO"
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 (73)*				
REMARK–	1	LOAD NAME–	2	25 PRINT "ELIZABETH"
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.

Computer commands were taught through a combination of instruction and execution. Use of the appropriate command words was cued, when necessary, with initial letter cues. When commands were correctly entered, appropriate functions were carried out by the computer. For example, typing the word HOME in response to the instruction *clear the screen* caused all information to be erased from the display screen.

Program writing was taught by a trial-and-error method whereby the patient was required to test the program using the RUN command after writing each new program line. If the desired outcome was not achieved, (i.e., the commands in the program were not executed as expected), prompts were provided for error detection and correction. Because of this contingent, interactive feature of the training programs, most commands were used repeatedly within a lesson and the number of responses varied across subjects and trials. In Table 2, the numbers next to the concepts and commands indicate the minimum number of times that each word had to be used in a single trial.

Two-hour training sessions were conducted twice weekly until perfect or near-perfect performance was attained. Two dependent measures were recorded: the number of trials to criterion and the number of hints per trial, the latter including both letter cues and direct prompts. Subjects returned to the laboratory 1 month after completion of initial training and returned again 7 9 months later, although some of the control subjects were unavailable for delayed testing. At each of these delays subjects received a single trial on Lessons 2 and 3. No intervening computer training or practice was provided. Because long-term retention was tested only on Lessons 2 and 3, we will report data from these two lessons; all subjects, however, successfully completed Lesson 1 before proceeding further.

RESULTS

Table 3 presents the data for all eight patients. The original learning and 1-month delay results for the four CHI patients appeared in an earlier report [7]. They are included here to facilitate comparison with the four new patients. As indicated in Table 3, all patients were eventually able to acquire the concepts and procedures required to perform basic functions on the Apple IIe microcomputer. They learned to display various kinds of information on the computer screen, remove unwanted data from the display, perform disk storage and retrieval operations, and write and edit simple computer programs. Furthermore, they demonstrated substantial retention of this knowledge over periods of up to 9 months.

Table 3. Performance of patients and controls on Lessons 2 and 3. Trials to criterion, range of hints during original learning, and number of hints required after delays of 1 month and 7–9 months

	Lesson 2				Lesson 3			
	Original learning		Long-term retention		Original learning		Long-term retention	
Patients	Trials to criterion	Range of hints	1 mo. delay	7–9 mos delay	Trials to criterion	Range of hints	1 mo. delay	7–9 mos delay
V.G.	14	23–0	3	8	7	17–0	3	12
G.X.	32	54–1	7	11	22	42–2	6	12
G.R.	54	59–2	7	11	39	60–10	10	11
C.H.	55	83–2	4	8	54	70–5	9	16
H.D.	10	39–1	1	2	12	36–3	—	10
W.K.	9	26–0	1	5	16	24–0	3	11
B.B.	27	85–0	8	6	14	46–0	12	16
B.Z.	72	50–0	6	2	59	54–2	3	11
Mean	34.1	52.4–0.8	4.6	6.6	27.9	43.6–2.8	6.6	12.4
Controls								
R.B.	5	17–1	10	14	4	26–0	0	7
S.B.	6	42–0	6	11	9	20–2	3	26
M.M.	15	73–2	2	—	10	29–0	6	—
B.D.	4	12–0	—	—	4	10–0	—	—
S.J.	7	34–0	8	8	4	26–1	8	11
G.M.	3	21–0	—	—	2	5–0	—	—
Mean	6.7	33.2–0.5	6.5	11.0	5.5	19.3–0.5	4.3	14.7

The learning exhibited by memory-disordered patients, however, was far from normal. They required many more trials than control subjects to reach criterial levels of performance. The mean numbers of trials to criterion on Lessons 2 and 3 are significantly ($P<0.05$) larger for patients (34.1 and 27.9) than for controls (6.7 and 5.5), *t*s $(12)=2.78, 2.67$. In addition, patients generally needed more hints to complete the first trial of each lesson (52.4 and 43.6) than did control subjects (33.2 and 19.3). This poorer initial performance by patients was attributable to their inability to take advantage of within-trial repetitions [7]. All patients, however, were able to achieve near-perfect final levels of performance; that is, the number of hints required approached zero in all cases.

There were no notable differences in original learning measures between the performance of the new patient group and that of the CHI patients. The new patients as a group tended to perform slightly better than the CHI group, although there was considerable between-subject variability. All patients learned the tasks. Etiology, therefore, does not seem to be a factor in the success of our procedures.

Severity of memory impairment may provide a better indicator of learning capability. The closed-head injury patient C.H. and the aneurysm patient B.Z. are the most severely impaired of the group in the sense that they scored zero on recognition memory tests and were unable to remember either their prior visits to the laboratory or their previous experiences with a microcomputer. They required the greatest number of trials on both lessons in order to achieve acceptable levels of performance. Note, however, that the encephalitic patient H.D. is an exception to this pattern. Despite her severe memory deficits and her low IQ, she learned the computer tasks as quickly as two of the highest functioning patients, V.G. and W.K. H.D.'s exceptional performance may be attributable to her extremely good attentional skills. The relatively poor performance of G.R., who has a moderate memory deficit overlaid with attentional problems, is consistent with this hypothesis.

The long-term retention measures reveal little forgetting even across a retention interval of 7–9 months. Whereas patients needed means of 52.4 and 43.6 hints to complete Lessons 2 and 3 on the first trials of original learning, they required only 6.6 and 12.4 hints respectively after the 7–9 month interval. Although some commands could not be immediately retrieved after the long delay, very little cuing was necessary to bring the information to mind. There were no differences in long-term retention among patients as a function of either etiology or severity of impairment. Even patients C.H. and B.Z., who had no recollection of ever having worked on the computer before, performed extremely well. Patients' knowledge, once acquired, was extremely durable in all cases. There is some suggestion of greater forgetting among control subjects than among patients. This apparent difference, however, can almost certainly be accounted for by the extensive overlearning experienced by patients as compared to controls.

DISCUSSION

In an earlier study [7], we demonstrated that patients who had memory deficits attributable to closed head injury could acquire the kinds of complex knowledge and skills needed to operate a microcomputer. The present report extends the generality of those findings by showing that (1) the method of vanishing cues is an effective technique for teaching complex knowledge to memory-disordered patients with etiologies other than head injury, and (2) the knowledge acquired under these conditions is retained by patients for very long periods of time. Note, however, that the learning exhibited by patients is not normal. Although they possess some residual learning abilities, their performance is quite clearly impaired relative to controls (see [7] for further disucssion).

Although knowledge of computers is potentially applicable outside the laboratory, we have not demonstrated in this study that laboratory-acquired knowledge can be applied by patients in a real-world domain. In other research, however, we have begun to investigate whether memory-disordered patients can acquire domain-specific knowledge in relevant everyday situations. A domain of considerable practical importance to patients with memory deficits is that relating to employment. Patients with memory problems have serious difficulties in obtaining or holding a job because of their inability to learn and remember even simple tasks. Using the vanishing cues method and extensive repetition, we have recently attempted to train one of the severely amnesic patients from this study (H.D.) to perform a complex computer data-entry job. She initially learned the job in our laboratory via the vanishing cues procedure and is now performing it in the workplace [6]. The job requires concentration, careful attention to detail, and precise execution of component operations. However, the procedures, like many of those required in computer-related jobs, are highly structured and invariant over time, characteristics that make such jobs repetitive and boring for the normal worker but ideally suited to the memory-impaired individual.

We believe that an approach to memory remediation that emphasizes the acquisition of domain-specific knowledge has the potential for significant impact on the lives of memory-impaired individuals. As we and others have argued elsewhere [5,16,23], approaches that attempt to restore memory in any general sense have thus far proven unsuccessful. Although our findings to date are encouraging for a domain-specific approach, many questions have yet to be answered. Further research in our laboratory is attempting to explore the limits of knowledge that can be acquired by amnesic patients and to identify other real-world domains in which to apply and test our techniques.

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