

Memory and the Hippocampal Complex

II. Is Memory a Multiple Process?

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FOR at least 75 years psychologists have debated whether there is a single mechanism for human memory or two separate mechanisms of differing permanence. William James, on the basis of introspective analysis, first defined two categories of memory, primary and secondary.¹ Primary memory dealt with the just-elapsed portion of an ongoing event, "... the rearward portion of the present space of time ..." Secondary memory served to recall events that had "... already once dropped from consciousness ..." Subsequent authors have renamed James' two memory mechanisms, calling the first "immediate," "short-term," or "recent" memory²⁻⁶ and the second "delayed," "long-term," or "distant" memory.^{2,3,7} Though the two postulated phases of memory have been rechristened, today there is less agreement than ever as to whether a "dualistic" or a "monistic" theory of memory is correct.

During the last decade a number of authors have noted that patients with bilateral lesions of the hippocampal complexes develop an isolated memory defect, with preservation of other cognitive functions.^{5,8-13} Not all aspects of memory are equally affected; while the patients are virtually unable to establish lasting new memories, they can remember relatively small amounts of information perfectly for sec-

onds or minutes if undistracted. This dissociation of preserved and impaired memory functions raises the possibility that one memory mechanism, dependent on the intactness of the hippocampal regions, is damaged while another anatomically independent mechanism is spared.

In the present study we wished to establish whether there was essentially normal function in one phase of memory and markedly impaired function in the other or whether there was merely a general impairment of all memory functions. A demonstration of markedly different levels of performance in two distinct categories of memory tests would provide strong confirmation of a "dualistic" concept of memory, with one phase anatomically linked to the hippocampal regions.

Five patients with memory defects due to bilateral lesions of the hippocampal complexes were compared with a group of 20 normal control subjects. Special tasks were designed to test immediate memory span and storage ability using comparable memoranda. Patients with hippocampal lesions showed a marked impairment of storage ability despite well-preserved immediate memory spans. The results supported the dualistic concept of memory, identified the limits of its two components, and confirmed that the hippocampal regions are an important anatomic substrate for memory storage.

Methods

Subjects.—Normal Controls: Twenty evening and summer-session students at Loyola University served as normal control subjects. Of the subjects 12 were male and 8 were female; their ages varied from 18 to 44, with an average age of 24. Many control subjects were taking an introductory

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TABLE 1.—Clinical Features in Patients With Hippocampal Lesions

Patient and Reference	Age	Etiology	Neurologic Findings at Time of Testing	Duration of Deficit	Electroencephalogram	Other Initial Laboratory Findings
L.C. ¹²	21	Herpes simplex encephalitis	Olfactory loss	4½ yr	Bilateral temporal slowing	Medial temporal-orbital frontal radioisotope scan positivity at onset; rising herpes simplex titer
V.F.	51	Trauma; temporal lobe epilepsy; right temporal lobectomy (partial)	Pallor of optic disks; left eye visual field defect	31 yr, head trauma; 8 yr postop	Mild right temporal slow and sharp activity; severe left temporal sharp activity	
A.R.	61	? Subarachnoid hemorrhage	None	3 mo	Severe left temporal slow and sharp wave activity; mild right temporal sharp activity	Bloody cerebrospinal fluid
M.H. ⁵	39	Bilateral temporal lobe excision for epilepsy (including hippocampi)	None	12 yr		
H.S. ¹⁴	33	? Herpes encephalitis with status epilepticus ? Anoxia	Right olfactory decrease	6 yr	Mild bitemporal sharp activity	

psychology course; but none had any familiarity with the test materials.

Patients: Five patients with known or presumed bilateral lesions of the hippocampal complexes were studied (Table 1). In each a severe memory defect was known to exist in the absence of dementia, confusion, dysphasia, or other evidence of impairment of the sensorium or intellect. One patient had undergone bilateral medial temporal lobe resection for intractable epilepsy (Patient M.H., previously reported by Scoville and Milner⁵); one patient with bitemporal epileptogenic foci, probably post-traumatic in origin, had undergone unilateral medial temporal lobe resection for control of seizures; two patients had had encephalitis, one proved (Patient L.C., previously reported by Drachman and Adams¹²) and one suspected (Patient H.S., previously reported by Talland¹⁴) to be due to herpes simplex; and one patient had suffered a sudden subarachnoid hemorrhage accompanied by a severe memory deficit and bitemporal electroencephalographic abnormalities. Four patients were men and one was a woman; their ages varied from 22 to 61, with an average age of 41.

An additional patient with bilateral lateral temporal (neocortical) excisions performed for the purpose of decompression following head trauma was examined as a comparable "operative control."

Testing Methods.—Normal controls and patients were given two special tests of memory function, the Extended Digit Span and the Extended Paired Light Span. In addition, all subjects received the Wechsler Adult Intelligence Scale and the Wechsler Memory Scale (Table 2). Detailed histories of the patients' memory defects were obtained

from family members, and all patients were examined neurologically; four of the patients had electroencephalograms at the time of the study.

Extended Digit Span.—This test consisted of two portions, a subspan and a supraspan phase. In the subspan phase random nonordered series of digits beginning with five-digit lengths were presented by tape recorder at the rate of one digit per second. Three different series of each length were presented to each subject; if one or more of the three were repeated correctly, the next longer series was attempted. When a subject failed to repeat correctly any of the three series of a given length, the number of digits in the next lower series was considered to be his "digit holding span" (DHS). In the supraspan phase the subject was then presented a different series of the same length as the one he had previously failed to repeat. Repetitions of the series (training trials) alter-

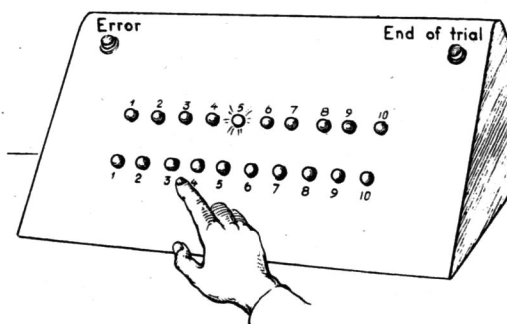


Fig 1.—Paired-lights console. Lights in the lower row are response pushbuttons.

nated with attempts by the subject to reproduce the series (testing trials) until a criterion of one perfect recall was achieved. For each testing trial the number of correct responses* was recorded, as was the total number of trials to criterion. No subject was allowed more than 25 trials to reach criterion, and the test was discontinued if this number of trials was reached without success. When a subject reached criterion, he was given successively longer series in the same fashion until he had correctly repeated each series up to 20 digits or failed. A subject's digit storage capacity was recorded as the longest series that he could repeat within 25 trials or where he had reached the maximum, as "20+."

Extended Paired-Lights (PL) Span.—This test paralleled the extended digit span test but utilized visual-spatial memoranda rather than auditory-verbal ones. A display and response panel (Fig 1) placed before the subject contained two horizontal rows of ten lights each, one above the other. The lower lights also functioned as pushbuttons which the subject could press to indicate his responses. Each presentation consisted of a training trial and a testing trial. In the training trial one upper and one lower light were simultaneously illuminated for one second, followed by a second paired-light display, etc, until all pairs in a given series had been presented. In the testing trial only the upper (cue) light was illuminated, and the subject had to respond by pressing the previously associated lower (response) light. Following each response, another cue light was illuminated until all pairs in the memorandum had been tested. The pairings and order of presentation were randomly designated; the order of presentation was changed from training trial to testing trial to avoid learning a response order. The subject was allowed to determine his own response rate and was informed of errors by a buzzer and a red light. The entire presentation was programmed on an eight-channel tape, using a tape reader and digital equipment for control of presentation and recording of results.

Each subject was presented increasingly long series, starting in the subspan phase with three paired lights. Three different series of each length were presented to each subject; if a correct response was obtained for one or more of the three, the next longer series was presented. When a subject failed to respond correctly to any of the three series of a given length, the next shorter series was considered to be his paired-light holding span (PLHS). In the supraspan phase the last series that the subject had failed was repeated, training trials alternating with testing trials. Six different orders of presentation were used at each

* Scoring Method: Correct first or last digit and any adjacent correct digits were scored as correct. Otherwise, digits were scored as correct only when three or more were in correct order. Inversion of digits and two adjacent digits in correct order received no score.

memorandum length to avoid learning of a response order. Series were repeated until the subject achieved a criterion of one perfect response; no subject was allowed more than 25 trials at each level in which to reach criterion, and the subject was considered to have failed if he reached this point without success. When a subject reached criterion, he was given successively longer series in the same manner until he had correctly responded to all memoranda up to ten paired lights or had failed. A subject's PL storage capacity was recorded as the longest PL series correctly performed within 25 trials or where he had reached the maximum length series as "10+."

Perseveration Score.—A "perseveration score" was computed for each subject in the supraspan phase of both the extended digit span and extended paired-light span tests. This was the percent of total trials in which identical numbers of correct responses were obtained on two or more adjacent trials. Although this is not an exact measure of perseverated responses, it closely reflects the number of trials in which identical responses were made.

Results

Standard Psychological Tests.—Wechsler Adult Intelligence Scale: The five patients with hippocampal lesions achieved a mean full-scale intelligence quotient of 119 compared with the control group mean IQ of 121; a *t*-test ($t=0.44$; $P=0.66$) reveals no statistically significant difference between the IQs of the two groups. Similarly, comparison of verbal and performance IQ scores shows no significant difference between the patient and control groups ($t=1.54$ and 0.90 respectively).

Wechsler Memory Scale: On this test the patients performed considerably less well than the controls, achieving a mean memory quotient (MQ) of 84 compared with the controls' mean MQ of 133. The difference between these scores is highly significant ($P<0.001$). Differences between patient and control group performance were significant on the Orientation, Memory Passages, Digits Backward, Visual Reproduction, and Associate Learning subtests; while there was no significant difference in the Digits Forward, Information, and Memory Control subtests. On the Associate Learning subtest the patients showed no evidence of improvement of performance during the three repetitions of the test material.

TABLE 2.—Results of Psychological Tests

Patient	Verbal IQ	Performance IQ	Full Scale IQ	Memory Quotient	Digit Holding Span	Digit Storage Capacity	Paired-Light Holding Span	Paired-Light Storage Capacity
L.C.	121	117	121	92	8	12	3	6
V.F.	132	116	120	93	8	10	4	6
A.R.	109	95	104	80	6	7	3	4
M.H.*	109	125	121	64	6	6	—	—
H.S.	128	129	130	90	7	8	3	6
Patients' mean score	120	116	119	84	7.00	8.60	3.25	5.50
Control subj mean score †	127	111	121	133	8.30	20.00†	4.05	9.95

* As determined by Wechsler-Bellevue Intelligence Scale administered in 1962 (Dr. B. Milner).

† Intelligence Scale and Memory Scale scores based on N=19..

Extended Digit Span.—(a) The mean digit holding span (DHS) for the control group was 8.30, while the DHS for the patient group was 7.00. The difference between these scores is not statistically significant by the *t*-test ($t=1.24$, $P=0.23$).

(b) The digit storage capacity (DSC) for the control group † was 20 digits or greater for all normal subjects. No patient had a DSC of greater than 12 digits, and the mean DSC for the patient group was 8.60. A χ^2 test shows the difference between patients and normal controls to be significant at less than the 0.001 level.

(c) In Fig 2 the number of trials required to reach criterion for numbers of

† Comparison of performance of the four oldest and four youngest control subjects (mean ages 35.5 and 19.3 respectively) by means of a χ^2 test showed no significant difference in performance on digit storage capacity or paired-light storage capacity tests.

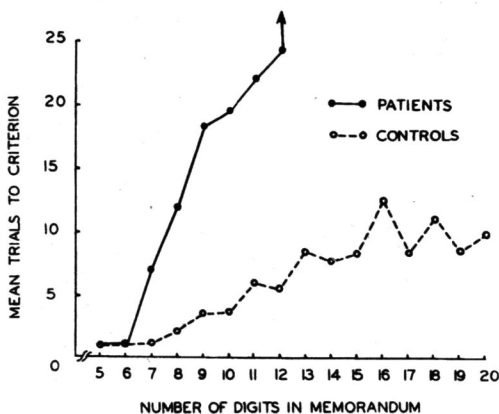


Fig 2.—Extended digit span: mean trials to criterion for subspan and supra-span memoranda. Patients with hippocampal lesions require many more trials than controls to achieve criterion with supraspan memoranda; no patient successfully recalled more than 12 digits.

increasing length is graphically represented. Although the digit holding spans are similar for patient and control groups, patients require many more trials than do controls to reach criterion with progressively longer memoranda. The slope of the supraspan phase of the curve is therefore much steeper for patients than for controls.

(d) In Fig 3 the mean number of digits correctly recalled on each successive trial is depicted for patients and controls. While controls show improvement with increasing numbers of trials, the patients show virtually no improvement.

Extended Paired-Light Span.—(a) The mean paired-light holding span for the control group was 4.05 pairs, while for the patient group it was 3.2 pairs. There is no statistically significant difference between these scores according to the *t*-test ($t=1.45$, $P=0.17$).

(b) The paired-light storage capacity for 19 of the 20 control subjects † was 10 paired lights or greater; one subject reached criterion at 9 but failed at 10. No patient had a paired-light storage capacity greater than 6, and the mean for the group was 5.5. The difference between patients and normal control subjects is significant at less than the 0.001 level using the χ^2 method.

(c) In Fig 4 the number of trials required to reach criterion for paired-light memoranda of increasing length is shown. The paired-light holding spans of patients are similar to those of controls. However, the patients require many more trials to reach criterion with supraspan memoranda than do controls.

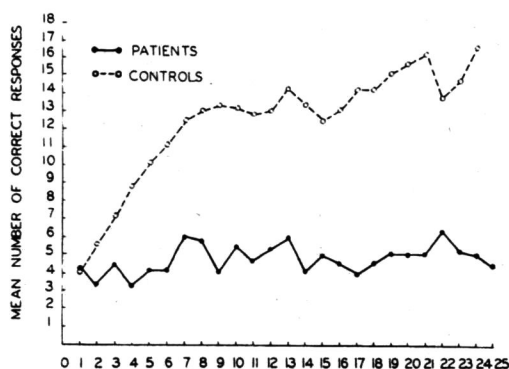


Fig 3.—Extended digit span: mean correct responses for successive trials with supraspan memoranda. In this storage phase of the test, normal controls showed evidence of improved performance on successive trials, while patients' performance did not improve.

(d) In Fig 5 the mean number of light pairs correctly recalled on each successive trial is shown for patients and controls. The curve for patients reveals no improvement with successive trials, while normal controls show progressive improvement.

Perseveration Scores.—On the extended digit span the patients had a mean perseveration score of 42.4%, while controls scored 29.3%. The difference is not significant ($t=0.58$; $P=0.57$). On the extended paired-light span the patients had a mean perseveration score of 30.3%, while that of the controls was 33.0%; again the difference is not significant ($t=0.39$; $P=0.70$).

Patient With Bitemporal Neocortical Lesions.—For comparison with the group of patients with bilateral medial temporal lesions, a patient with bilateral lateral temporal lesions was studied. This patient's full-scale IQ was lower (100) than that of any patient with medial temporal lesions and showed a marked disparity between verbal (118) and performance (76) scores. Although a marked emotional response prevented this patient from completing the extended digit span, she reached 15 digits (better than any of the medial temporal patients) before refusing to continue. Her PL storage capacity was 10+, comparable to the normals and superior to any of the patients with medial temporal lesions. Her performance on other tests of cognitive functioning, however, was worse than that of the medial temporal patients.

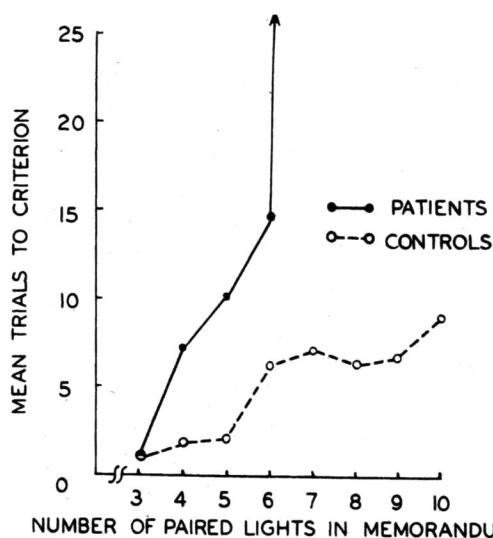


Fig 4.—Paired-lights span: mean trials to criterion for subspan and supraspan memoranda. As with digit span, patients required many more trials than controls to achieve criterion with supraspan memoranda; no patient successfully recalled more than 6 paired lights.

Localization of Lesions.—In only one patient, M.H., was the localization of the lesions directly established by visualization. His lesions were produced surgically; most of the hippocampal complexes were known to have been removed at operation.⁵ In the other patients localization of the lesions has been by indirect means. Patient L.C. suffered from herpes simplex encephalitis, a disease with a predilection for attacking hippocampal structures; in addition, an arsenic scan and an EEG indicated predominantly medial temporal lesions.¹² Patient H.S. was presumed to have had herpes encephalitis; EEG also indicated bilateral

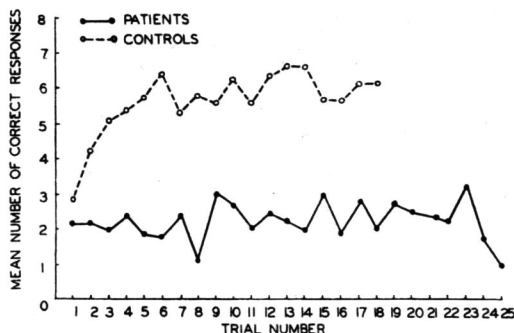


Fig 5.—Paired-lights span: mean correct responses for successive trials with supraspan memoranda. As with digit span, normal controls showed evidence of improved performance on successive trials, while patients' performance did not improve.

temporal lobe involvement.¹ Patient A.R. had a subarachnoid hemorrhage; and V.F. sustained head trauma. In these patients EEG evidence indicated lesions of the temporal lobes bilaterally, with either slow or sharp activity seen.

Despite the imprecision of localization of the lesions in some cases, the amnesic syndromes were all closely similar. The behavioral uniformity and the probability of bilateral lesions of the hippocampal regions justified the grouping of these patients for study.

Comment

"Extended-Span" Memory Tests.—The single-trial presentation of memoranda with immediate recall has been used for more than 75 years to define an "immediate memory span" (IMS), usually in the form of a digit span.¹⁵ The gradual lengthening of memoranda beyond the IMS has not been systematically studied, although in 1943 Zangwill briefly reported on a few such experiments in a variety of brain-damaged subjects.¹⁶ In the present study extended-span memory tests were used because they provide a method of separating pure memory "storage" from IMS by varying only the length of the memoranda. Storage is thereby tested without introducing the additional variable of a delay interval.

When subspan memoranda are employed, the subject requires only a single trial for perfect recall. An evanescent "holding mechanism" primarily enables him to recall and repeat each memorandum. Although there is no way of preventing some more lasting "storage" from taking place—and it probably occurs to some extent in all normal subjects,¹⁷ storage is not needed for the successful recall of subspan memoranda.

When supraspan memoranda are used, however, the subject requires multiple repetitions to achieve perfect recall; he must accumulate information with successive exposures. Some memory "storage" must take place from trial to trial, enduring at least throughout the series of trials until the final correct recall. The performance of normal subjects on the supraspan portions of both the digit and paired-light tasks demonstrates

the progressive accumulation of information (ie, storage) upon repetition; in Fig 3 and 5 the increasing numbers of correct responses on successive trials are shown graphically.

Results in Patients With Bilateral Hippocampal Lesions.—Two types of extended-span memory tests, digit and paired-light spans, were presented to patients with bilateral hippocampal lesions and to normal control subjects. With single-exposure testing the two groups were able to recall memoranda of approximately the same maximum length. When supraspan memoranda were used and multiple repetitions given, the normal subjects were able to recall as many as 20 digits and 10 paired lights; by contrast, all the patients had great difficulty recalling memoranda in excess of their immediate memory spans, and none succeeded beyond 12 digits or 6 paired lights. Thus, it is clear that patients with bilateral hippocampal lesions show a marked deficit of storage ability, while the holding mechanism, or IMS, is unimpaired.

The observation that storage ability is impaired does not define precisely how or why information is not stored. One explanation that has been offered is that perseveration of errors (in experimental animals [18-20]) accounts for failure to store new material. In the present group of patients, however, perseveration of errors was not noted to any greater degree than in the control group; in the digit span patients perseverated insignificantly more, and in the paired-light span insignificantly less than controls. The most likely remaining explanation is that storage merely fails to take place because an important locus or connection for this process has been damaged.

Comparison With Other Observations of Patients With Hippocampal Lesions.—If impairment of storage with preservation of IMS are the major results of bilateral hippocampal lesions, the behavioral abnormalities noted by other authors should be interpretable in these terms. The anecdotal observations that have been recorded are readily explained in this way: because of the preservation of IMS, these patients are able to follow a sentence, carry on a con-

version, or play a game of cards; because of the impaired storage ability, they may be unable to remember the date, learn new names, or recall whether they have eaten recently.^{9,12,21}

In three other test situations patients with hippocampal lesions have also shown impairment of performance: immediate recall of "complex" memoranda, such as difficult paired associates; recall following distraction; and recall following a delay.^{5,8-13} These deficits may also be explained on the basis of the impairment of storage and the normal characteristics of the remaining holding mechanisms (IMS).

Complex memoranda may be difficult for patients with hippocampal lesions because they behave like supraspan memoranda. When the length of a memorandum is the only variable, a relatively reliable IMS can be determined; longer memoranda are then supraspan, shorter ones are subspan. When other characteristics of the memorandum are changed, length may become a less important parameter. For example, it may be easier to remember ten words in English than two in Chinese; or a polysyllabic word rather than a few unrelated letters.²² The amount of information in a memorandum (termed "chunks" by Miller²³) may thus be independent of its actual length. The number of chunks of information in "complex" memoranda, such as difficult paired associates, is probably large compared with their length. Since the IMS can hold only a limited number of chunks of information, a few difficult paired associates can readily exceed the span and require the use of the storage mechanism for successful recall. In patients with hippocampal lesions who have impairment of storage, recall of difficult paired associates is thus poorly performed.

Either delay or distraction between presentation and recall of a memorandum may produce impairment of performance in patients.^{8,9} However, the effect of the delay interval is not consistent; relatively short (subspan) memoranda may be recalled for periods of up to 15 minutes, if the patient's attention is not distracted,⁸ or may be forgotten in a few moments. Similarly, the effectiveness of a given form of distraction

varies widely. Delay or distraction tend to produce either little effect or total loss of the memorandum in patients with hippocampal lesions. This "all-or-none" effect reflects the characteristics of the holding mechanism functioning in the absence of storage: immediate memory span is evanescent in duration, lasting for no fixed period of time, but only as long as the patient's attention is directed toward the memorandum. If his attention is redirected, even for a moment, all recollection of the memorandum is promptly lost. Either the passage of time (with its endogenous and exogenous distractions) or a purposely induced distraction may produce this redirection of attention.

In addition to the memory deficits already noted, retrograde amnesia has been observed consistently in patients with bilateral hippocampal lesions. The period of amnesia, which is usually incomplete, has varied from a few days to four years.^{5,8,9,24} The occurrence of retrograde amnesia points out another aspect of storage in the hippocampi: not only are they essential to the process of forming new memories, but they may also serve as a temporary storage area for the memories themselves. Experimental observations on the effects of hippocampal lesions made at various intervals after a learning experience support the view that the hippocampi serve as a temporary storage area. In mice hippocampal lesions made within a few days after learning a maze caused severe impairment in performance; lesions made six or more days after learning produced no impairment in maze-running.²⁵ The extent of the retrograde amnesia occurring with hippocampal lesions may thus correspond to the period of time during which memories are stored within the hippocampi before permanent storage elsewhere.

Comparison of Human and Experimental Animal Observations.—Drachman and Ommaya have previously reviewed the behavioral effects of bilateral hippocampal lesions in experimental animals.²⁶ They found general agreement in the literature that tasks involving acquisition or retention of behavior consistently showed impair-

ment. In those instances where investigators had concluded that "short-term memory" was impaired, Drachman and Ommaya found that the defect was actually of acquisition or retention of a task involving the ability to respond after a time delay. Whenever animals were able to acquire or retain a "short-term memory" task, ability to respond after a delay interval was unimpaired.

The type of task used to test acquisition in experimental animal studies has only been reported in a single human subject with bilateral hippocampal lesions. In a study of maze-learning, Milner²⁷ and Corkin²⁸ found that the ability of their hippocampectomized patient to learn a maze pattern on multiple trials was markedly impaired.

In the present study multiple trials were given to patients in an "acquisition" task where supraspan memoranda of two modalities were to be learned. The "problem-solving" aspects of the tasks were eliminated by explanations given in advance; the tests were purely of storage ability. The defect in storage that was found in the patient group corresponded closely to the impairment of acquisition seen in monkeys.

The preservation of IMS in patients with hippocampal lesions provides an explanation for the ability of experimental animals to perform delayed-response tests correctly. If the memoranda used in the animal studies are of subspan length and the animal's attention is directed toward the memorandum, he should be able to bridge a delay interval; these have indeed been the conditions of the successfully performed delayed-response tasks.

Application of Observations to Current Theories of Memory.—The impairment of storage and preservation of immediate memory span in patients with bilateral hippocampal lesions implies a theory of memory in which "short-term" and "long-term" memory mechanisms are separate, with separate anatomical locations. A number of contemporary investigators studying normal subjects have also concluded that there are (at least) two different memory mecha-

nisms.^{6,17,20} Others have contended that all memory involves a single mechanism and particularly that no "short-term" memory mechanism exists.^{2,3,20} The latter investigators have claimed that "short-term" memory follows the same rules that have been established for "long-term" memory and that the two mechanisms are therefore identical.

In order to compare different studies of "short-term" and "long-term" memory, it is necessary to determine whether other authors have used the same definitions and tested the same functions. The present study provides the following definitions.

"Short-term" memory (IMS) deals only with subspan memoranda, evanescently, as long as the subject's attention is directed toward the memorandum. Recall following redirection of attention (ie, by sufficient distraction or delay) depends upon a more permanent storage mechanism.

"Long-term" memory (storage) deals both with supraspan memoranda held for long or short intervals and with subspan memoranda recalled following the redirection of attention.

Thus, the use of subspan memoranda does not define a "short-term memory" task. If delayed recall is tested with subspan memoranda, "long-term memory" may be used.

Keppel and Underwood³ and Melton² have carried out studies of "short-term memory" according to the method of Peterson and Peterson.³¹ With this technique a subspan memorandum is presented, the subject counts backward by threes during a delay interval and finally recall of the memorandum is attempted. Keppel and Underwood have shown that proactive inhibition affects the memory of single items just as it affects lists³; and Melton has shown that the recall of subspan items decays with the passage of time in the same manner as supraspan items.² Both authors have used this evidence to indicate that "short-term" and "long-term" memory are a single mechanism.

Reinterpreting this data in light of the definitions suggested by the present study, it appears that "short-term memory" may

not have been tested. Instead, these investigations have studied storage ("long-term memory") of subspan memoranda and have shown that it follows the same rules as for storage of supraspan memoranda.

A similar problem is raised in the interpretation of a recent study by Hebb.³² This investigator had initially felt that "short-term" and "long-term" memory were separate mechanisms, the manifestations of "activity traces" and "structural traces" operating at a cellular level.³³ Anticipating that normal subjects would use the transient "activity traces" to recall digit spans, he conducted the following experiment: Thirty 9-digit numbers were presented in sequence with every third 9-digit number (the first, fourth, seventh, etc.) the same. If a completely transient "activity trace" were used, performance on all 9-digit numbers in the sequence should be the same. However, performance on the repeated number improved, while performance on the other numbers remained the same.³² While Hebb suggested that a third memory mechanism would have to be postulated, other authors have concluded that this experiment supports a single mechanism of memory.^{2,30}

On close examination this experiment is much like the repetition of supraspan numbers in the present study, except for the interpolation of other 9-digit numbers between the repeated ones. Despite the interference produced by the interpolated numbers, Hebb's normal subjects were able to learn supraspan numbers on repetition just as in the present study. This can be interpreted as showing that "long-term memory" (storage) proceeds concurrently with "short-term memory" in normal subjects regardless of the nature of the memoranda.

Summary

Five patients with known or presumed bilateral lesions of the hippocampal regions were studied to clarify the nature of the memory defect. Two new memory tasks were devised in which the length of a memorandum could be gradually increased from subspan to supraspan lengths. It was shown that the patients' immediate memory spans

(IMS) were normal compared to a group of 20 control subjects. However, the patients showed severe impairment in learning supraspan memoranda even after multiple repetitions. It was concluded that this indicates impairment of storage ability in patients with bilateral hippocampal lesions. No evidence of perseveration of errors was noted. These findings support a pluralistic theory of memory, since "short-term memory" (IMS) is unimpaired while "long-term memory" (storage ability) is impaired when specific areas of brain are damaged. The relation of these findings to experimental animal studies is discussed.

Drs. Raymond Adams, Maitland Baldwin, Herbert Lansdell, Brenda Milner, Ayub Ommaya, W. Beecher Scoville, George Talland, and Maurice Victor provided patients with hippocampal lesions for this study; Messrs. Raymond Daly and Anthony I. Schuham performed some of the psychological testing.

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THE USES OF ANGER

Any man can be angry, for that demands no skill. But to be angry with the right person, in the right degree and at the right time, for a right reason and in a right way, lies in the power of few, and is very difficult.—Aristotle