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SOME ADDITIONAL QUANTITATIVE OBSERVATIONS OF IMMEDIATE MEMORY IN A PATIENT WITH BILATERAL HIPPOCAMPAL LESIONS*

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Abstract—Additional behavioral data are reported on a well-documented patient who had undergone bilateral medial temporal-lobe resection. After a brief interruption from a visual discrimination task, he was unable to describe accurately what he had been doing; yet his subsequent performance was quantitatively similar to his earlier one. With verbal material, his delayed matching-to-sample performance was unimpaired up to 40 sec, the longest delay tested. With nonverbal material that required the patient to devise his own verbal coding, the sample stimuli lost control over his behavior after delays of 24–32 sec.

Although other factors undoubtedly contribute to the patient's forgetfulness, the suggestion was offered that his failure to use verbal coding plays an important role in preventing him from extending his immediate memory span.

THE RELATION between memory disorder and hippocampal damage has received its most detailed and perhaps strongest empirical support from extensive studies of SCOVILLE and MILNER's Case H.M. [7, 8]. This patient, who had a long history of incapacitating seizures which were not controllable by medication, underwent a radical bilateral medial temporal-lobe resection in the hope of lessening his seizures. The seizures did indeed lessen in frequency and severity after the operation, but the patient has shown a profound post-operative memory disturbance. SCOVILLE and MILNER described H.M. as follows: "In summary, this patient appears to have a complete loss of memory for events subsequent to bilateral medial temporal-lobe resection . . ., together with a partial retrograde amnesia for the three years leading up to his operation; but early memories are seemingly normal and there is no impairment of personality or general intelligence."

Dr. MILNER and Dr. SCOVILLE very kindly made this patient available to us for a brief period of study in June, 1966,† approximately 12 years after he had undergone the operation. He showed little change in his previously-reported severe loss of memory for recent events. For example, he expressed an inability to remember events that had happened only a few minutes previously; he failed to recognize people with whom he had recently spent many hours; and he was unable to name the hospital to which he had just come or the places he had been during the previous few days.

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We report here some additional quantitative behavioral investigations of H.M.'s immediate memory.

APPARATUS AND GENERAL METHOD

The apparatus used throughout these studies has been described in detail by SIDMAN and STODDARD [9]. The subject worked in a well-ventilated room, approximately 5-ft square, with sound-resistant walls and door. He sat before a stimulus-display and response panel composed of nine windows, which were arranged in a 3 × 3 matrix and divided by ¼-in. barriers. Each window was a 2 × 2 in. square of translucent plastic onto which stimuli could be projected from the rear. When the subject pressed a window, he operated a switch mounted behind it and delivered a signal to the electronic programming and recording devices. Because of their switching action, the windows are commonly called "keys." Stimuli to be presented on each trial were photographed on 35mm color film and projected as slides. Motor-driven shutters behind the keys controlled the presentation and removal of the stimuli. All conversation in the experimental room was recorded on tape.

When the subject pressed a correct key, the shutters closed, chimes rang, and automatic devices dispensed a penny. One and one-half sec later a new slide was presented. When the subject pressed an incorrect key, the projector advanced to a new slide as usual, but there were no chimes or other rewards. The position of the correct key always changed from trial to trial.

The stimuli projected on the keys, and procedural modifications, will be described in conjunction with the results.

RESULTS

Our initial aim was to determine the limits of H.M.'s ability to distinguish simple forms, circles and ellipses, and then to determine how well he retained this discrimination after he had been distracted briefly from the task.

Preliminary learning

To acquaint H.M. with the general procedures, he was first given a series of 10 slides, each of which projected a black outline of a circle and a bright yellow background onto one of the keys; the other keys of the matrix were dark. With no verbal instructions, but with pennies as rewards for correct choices, he learned quickly to press the circle. H.M. was then given a set of 10 slides in which each of the formerly dark keys now had a relatively flat ellipse on a bright background. He made no errors as he continued to select the circle and reject the ellipses on each trial. The ellipses had the same horizontal axis as the circle, but the vertical axis of the ellipses was smaller. The ratio of vertical to horizontal axis of the ellipses was 0.53.

H.M. was then given a series of slides in which the vertical axis of the ellipses lengthened from trial to trial; the axis ratio of the ellipses gradually approached 1.00, making them more like circles. Details of the procedure for determining a subject's circle-ellipse difference threshold have been described elsewhere [9]. H.M. was able to distinguish the circle from ellipses that had an axis ratio of 0.93. Although our normative data are still incomplete, they indicate that this is a relatively fine discrimination, and that the task reveals no gross perceptual deficit in H.M. His performance on the circle-ellipse discrimination demonstrated that his choice behavior was governed by the continuum of ellipse sizes until the axis ratio of the ellipses became larger than 0.93. The next experiment provides a more sensitive measure of the degree of stimulus control and permits quantitative analysis of at least one aspect of retention.

Stimulus control and retention

In the preliminary learning procedures, all the ellipses on a given slide had been the same, so that the circle could be compared with only one size of ellipse at a time. H.M. was next given a set of 32 slides, each of which projected a circle onto one key and one of seven different ellipses onto each of the other keys. (The center key was dark.) The ellipses on each slide had axis ratios of 0.74, 0.77, 0.80, 0.83, 0.86, 0.89, 0.91, and 1.00 (circle). H.M. was rewarded when he selected the circle. The circle and each of the ellipses changed in key position on consecutive trials. This set of slides will be called the *discrimination-gradient series.*

The results of H.M.'s first exposure to the discrimination-gradient series appear in Fig. 1A. He selected the circle 17 times, the 0.91 ellipse 11 times, the 0.89 ellipse 3 times, and the 0.86 ellipse once. The relatively steep gradient indicates that his behavior was controlled for the most part by the stimulus dimension correlated with reward. If there were no relation between his choices and the size of the ellipses, the gradient would have been flat. If his responses were completely controlled by ellipse size, he would have selected the circle every time. H.M.'s circle-ellipse threshold of 0.93 had indicated that he was capable of distinguishing all the ellipses in the discrimination-gradient series from the circle.

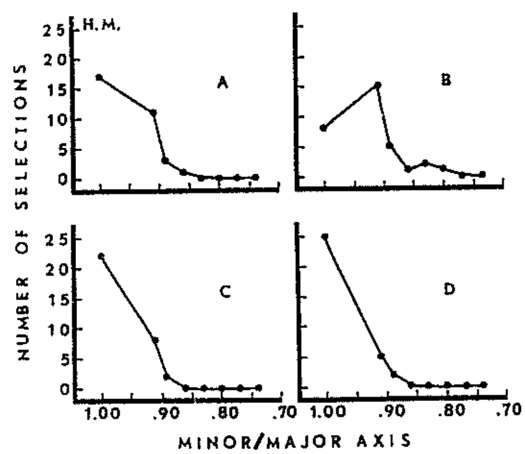

FIG. 1. H.M.'s circle-ellipse discrimination gradients, showing the number of times he selected each form. A and C are original gradients; B and D are the gradients after H.M. was interrupted.

The next step was to determine whether there would be any loss of stimulus control if H.M. was interrupted in his task. After completing the set of 32 slides, he was asked to count the pennies he had received. Then the experimenter (E) asked him what he had done to earn the pennies:

H.M: Well, let's see. Something would flash up there and the idea was to pick out one of those squares and to point it toward dark. To tip it—to hit it with my finger tip and to match up. Each time the two matched a penny would drop in.

E: Each time the two matched?

H.M: The two matched.

E: Uh-huh. What was on them?

H.M: X.
E: X was on them?
H.M: Yeah.

A few minutes later:

E: Can you tell me once more what you did to earn all those pennies?
H.M: Well, one of those would flash up and actually I made a decision to point or to hit one of them with my finger tip . . .
E: What were you pointing to—what were you pressing over there?
H.M: Well, one of these would light up and get one of them matched and every time one would match, of course, a penny would drop in.
E: What did the one that matched look like?
H.M: Cross.
E: A cross. Uh-huh. A plus sign?
H.M: Uh-huh.
E: Or a multiplication sign?
H.M: Well, you'd say, uh, it wouldn't be multiplication—addition.

Without any further communication, the first slide of the discrimination-gradient series was presented on the keys again, and H.M. went through the set a second time. His performance is summarized in Fig. 1B. The gradient reveals some loss of stimulus control—the 0.91 ellipse was selected more often than the circle—but the fact that his most frequent choice was the ellipse most closely resembling the circle indicated that H.M.'s behavior was still under the control of the same stimulus dimension. This, of course, would not be unusual were it not for his incorrect verbalization of the task just before producing the gradient of Fig. 1B.

This finding illustrates an important methodological point. If we had simply recorded the number of times H.M. correctly chose the circle, his score would have decreased from 17 to 8. A score of 8 is only slightly greater than one would predict if his choices were random. We would have been tempted to conclude that the interruption between series A and B had caused H.M. to forget the task. However, testing the gradient of stimulus control revealed that H.M.'s behavior was still governed by the relevant stimulus dimension, even though his accuracy had decreased.

The experiment was then repeated. H.M. was again given 10 preliminary slides on which he had only to select the circle from seven flat ellipses, all of which were the same. This served to reinstruct him without verbal communication. Then he was given the set of discrimination-gradient slides twice more, and the data from the second set appear in Fig. 1C.

Immediately after the last trial, H.M. was asked, "What were you doing that time?"

H.M: Get the circles that were round . . . Some were oval shaped and definitely the roundest one.

After this accurate description he counted his pennies, and two minutes later he was asked again to tell what he had done to earn the pennies:

H.M: Well, I pressed matching up to that would be exactly alike of, uh, well, crosses . . . There would be several of them on there, but two of them would be exactly alike . . . Pointing to one of them would naturally mean that there was another one just like it.

One-hundred seconds later, H.M. started the set of 32 slides again. Figure 1D shows the gradient. This time, there was no loss of accuracy; the gradient was the sharpest we had seen. Clearly, the performance for which H.M. had appeared amnesic in his oral account was perfectly intact when measured by the gradient of stimulus control.

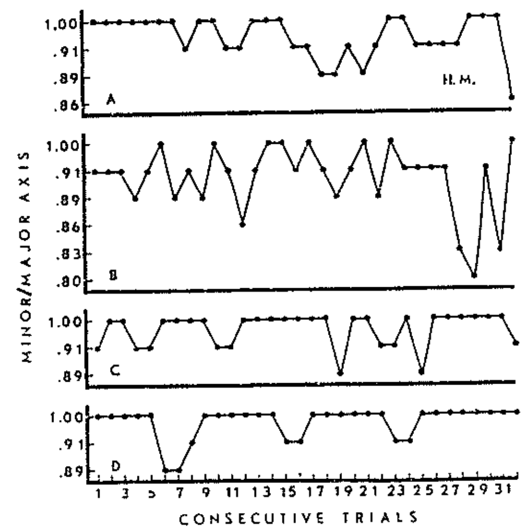

FIG. 2. Trial-by-trial records of the forms chosen by H.M. in the discrimination-gradient series. The letters A, B, C, and D indicate the same series as Fig. 1.

It might be supposed that H.M. actually had lost the ability to perform the task but had relearned it rapidly by means of the information the pennies gave him. This possibility is ruled out by Fig. 2, which shows his selections on each consecutive trial of the four experiments. He was accurate even at the beginning of each set.

Delayed matching-to-sample

The next procedure, matching-to-sample, permits a more precise assessment of short-term memory. A stimulus is first projected onto the center key of the matrix, the outer keys remaining dark. When the subject presses the center key, stimuli then appear on the outer keys. The subject's task is then to press the outer key that contains the same stimulus as the center key. The stimulus on the center key is the *sample*; the stimuli on the outer keys are the *choices*.

In *simultaneous matching*, the sample remains visible after the choices appear. In *delayed matching*, the sample disappears when the subject presses the center key, and he must remember the sample in order to select the matching stimulus. With zero-delay, the choices appear as soon as the sample disappears; with delays greater than zero, the sample disappears but stimuli do not appear on the choice keys until some time later.

The *adjusting-delay* procedure starts with zero-delay; each time the subject chooses correctly, the delay increases on the next trial; if he makes an error, the delay decreases on the next trial. By using the adjusting-delay procedure, it is possible to run a quick check on the limits of the subject's ability to remember the sample.

Two types of stimuli, on two separate series of slides, were used to probe H.M.'s immediate retention with the adjusting-delay procedure. The first set of stimuli consisted of combinations of three consonants (trigrams). The incorrect choices on each trial were all the possible combinations of the same three letters that appeared on the sample key. A second set of stimuli consisted of eight different ellipses. All of the ellipses appeared as choices on every trial, but the smallest and largest were never used as samples.

The results appear in Fig. 3. With trigrams, the delay between sample disappearance and choice presentation increased by 4 sec after each correct match, and would have decreased by 4 sec after each error. H.M. had no difficulty remembering the trigrams for as long as 40 sec.

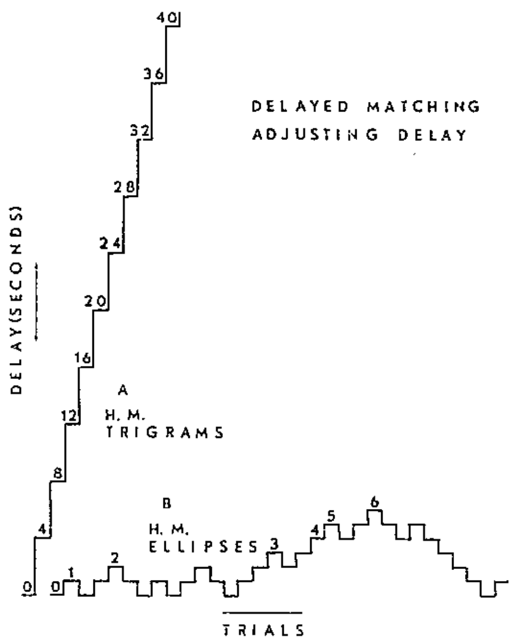

FIG. 3. Delay periods on consecutive trials of the adjusting delay series. Each delay is identified the first time it occurs in each series.

The ellipses gave quite a different result. H.M. had great difficulty when the increment of delay was 4 sec. Therefore, the progression was reduced to steps of 1 sec. H.M.'s best performance in three exposures to the delayed ellipse-matching procedure appears in Fig. 3. The longest delay he achieved correctly was 5 sec, and that only once in four trials.

Again, we might have arrived at a misleading conclusion if we had used only the dichotomous classification—errors vs. correct choices—upon which Fig. 3 is based. As in the discrimination-gradient series, a slight shift in accuracy at the longer delays could produce many errors without necessarily indicating a loss of stimulus control. Therefore, we gave H.M. a lengthy series in which he went through 48 trials of simultaneous ellipse-matching, followed in succession by 48 trials each of zero, 8, 16, 24, and 32-sec delays.

The curves of Fig. 4 summarize H.M.'s performance. The scale values on this figure require some explanation. The ellipses had axis ratios of 0.17, 0.31, 0.39, 0.46, 0.61, 0.77, 0.89, and 1.00. On every trial we ranked each of the eight possible choices with respect to its deviation in size from the sample. For example, if the 0.61 ellipse was the sample, values of +1, +2, and +3 were assigned to the larger choices, 0.77, 0.89, and 1.00, respectively; values of −1, −2, −3, and −4 were assigned to the smaller choices, 0.46, 0.39, 0.31, and 0.17, respectively. The correct choice, since it was the same as the sample, was assigned a value of zero. If the 0.31 ellipse was the sample, the 0.17 ellipse was ranked -1, and each of the others was ranked $+1$ to $+6$ progressively. The two extreme ellipses were used as choices, but never as samples.

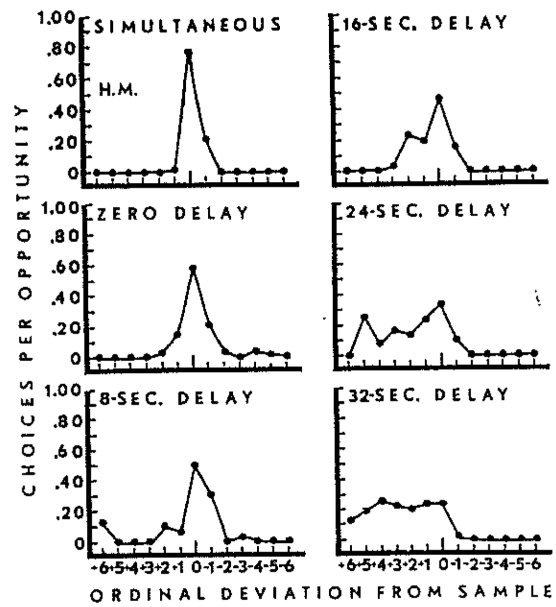

FIG. 4. Gradients of stimulus control as a function of the delay in the delayed ellipse-matching series. See text for explanation of coordinates.

After ranking the choices on each trial in terms of their ordinal deviation from the sample, we simply counted the number of times the subject selected each deviation. Note that there was only one ellipse smaller than 0.31, two smaller than 0.39, etc.; similarly there was only one larger than 0.89, two larger than 0.77, etc. Therefore, the number of opportunities for the subject to deviate a given number of steps from the sample ellipse depended on the size of the sample. We divided the number of times the subject selected each deviation by the number of opportunities he had to make each selection. This yielded the ratios scaled on the ordinates of Fig. 4. The ratio corresponding to the abscissa value of zero represents the proportion of the subject's opportunities on which he matched the sample correctly; data for all the different samples are combined. The value at -1 represents the percentage of the subject's opportunities on which he selected the ellipse next smaller in size than the sample. The remaining values follow accordingly, the positive numbers indicating ellipses that were larger than the sample.

With simultaneous matching, which allowed H.M. to compare sample and choices directly, the stimulus control was quite precise. H.M.'s few errors were selections of ellipses closest in size to the sample. There was some loss of accuracy at delays of zero, 8, and 16 sec, but his choices were still clearly controlled by the sample stimuli. The curves are sharply peaked at the sample and the errors decrease in an orderly fashion as the choices differ more from the sample.

H.M.'s choices were still controlled to some extent by the sample stimuli after delays of 24 sec, but he began frequently to select ellipses larger than the sample. This trend became dominant at the 32-sec delay, and all but obliterated any evidence of stimulus control. When 32 sec intervened between sample and choice, H.M. confined his choices almost exclusively to the larger ellipses. As the nearly flat gradient between zero and +6 indicates, the choices of the larger ellipses were only minimally related to the sample ellipses. This pattern of behavior would be expected if H.M. ignored, or forgot, the sample, and simply distributed his choices nearly randomly among the larger ellipses.

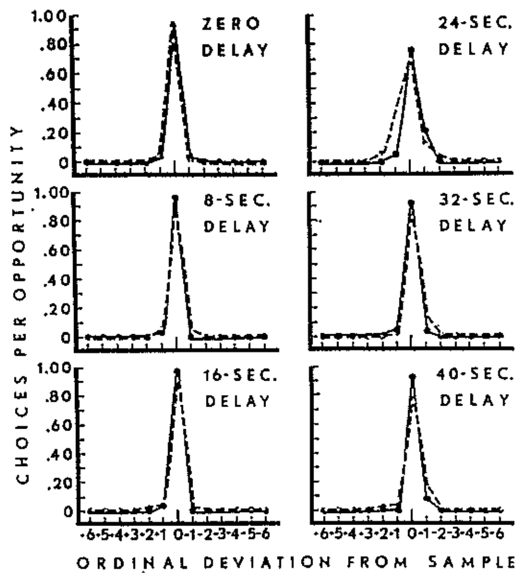

FIG. 5. Gradients of stimulus control as a function of the delay in the delayed ellipse-matching series for two normal children.

The deterioration of the relation between H.M.'s behavior and the sample ellipses at delays of 24 and 32 sec is not characteristic of the normal performance. Figure 5 shows the delayed ellipse-matching data of two normal children, 9.5 and 12 years old. The procedure was the same except that the delay intervals were presented in a mixed order in blocks of 8 trials; there was no extensive testing on simultaneous-matching; and delays of 40 sec were added to the series. Like older normal subjects, and unlike H.M., these children showed no evidence of deterioration at delays up to 40 sec.

DISCUSSION

H.M. was unable to describe the circles and ellipses to which he had been responding. Yet, these same stimuli were subsequently found to control his key-pressing behavior quite precisely (Fig. 1). MILNER [3] has reported a related observation. On a mirror-drawing task, extending over a three-day period, each new day found H.M. completely unaware that he had done the task before. Yet, his learning curve was normal, beginning on each new session at the same level he had reached on the previous day.

The two sets of findings, ours and MILNER's, raise the problem of how to specify H.M.'s behavioral deficit. One classification might be in terms of testing methods. It is well known that if we are asked to recognize something while it is present, we are more likely to remember it than if we are asked to recall it while it is absent. H.M. was unable to describe the circles and ellipses in their absence, but he reacted appropriately when he had simply to select one from the others. But the distinction does not hold true for the mirror-drawing. H.M. had the mirror apparatus before, him, as in a recognition test, when he could not remember it.

Both sets of data are consistent in demonstrating an absence of stimulus control over the subject's verbal behavior, while simultaneously demonstrating retention of stimulus control over perceptual-motor behavior (mirror-drawing) or simple perceptual behavior (circle-ellipse discrimination). Is it possible that H.M.'s deficit is specific to verbal behavior?

An unqualified answer to this question would undoubtedly oversimplify the true situation. H.M. is also unable to find his way home or to learn visual and tactual mazes [1, 4]. Yet, the learning of sequential tasks such as these is certainly facilitated if a person aids himself by devising a system of verbal labels or mnemonics. In comparison with those who do devise such a system, a person who cannot, or does not, may be expected to show a learning deficit.

H.M.'s brief retention of the sample ellipses (Fig. 4) raises the possibility that a failure to develop systems of verbal mediating behavior may play a significant role in his memory deficiency. All of our normal subjects have reported that they devised a coding system that enabled them to match the sample ellipse even after it had been withdrawn from view. The systems varied from subject to subject, but they all involved a descriptive series of words such as, "largest, smallest, next-to-largest, next-to-smallest, middle-sized," etc., or numbers from one to eight. Having applied a coding label to the sample, they retained the code word and applied it subsequently to the choices.

Whether H.M. devised such a coding system is problematical. Since he was no longer performing the task appropriately at the end of the experiment, there was nothing to be gained by asking him. Other features of H.M.'s behavior, however, suggest that he does not characteristically develop such self-help systems. He has never been observed to write notes to himself as reminders, to use maps to help him find his way from place to place, to use a calendar watch to ascertain the date, or even to ask anyone to accompany him so that he might enjoy movies and other entertainment or so that he might find his way to a place of employment. All of this behavior is lacking in spite of the fact that H.M. expresses an awareness of his memory difficulty [5].

It is not possible to ascertain conclusively from existing data whether H.M. is only imperfectly capable of initiating such behavior, or is not adequately motivated to do so, or does not take the trouble because he would then forget the supplementary devices themselves. MILNER [2] has noted that H.M. was able, by devising an elaborate mnemonic scheme, to remember a three-digit number for 15 minutes, but forgot it as soon as he was distracted.

PRISKO [6] tested H.M. on a somewhat different matching task which, in common with our delayed ellipse-matching, used stimuli that varied along continuous dimensions and were not verbalizable except by means of specially devised codes. On this task, also, H.M.'s performance was markedly inferior to that of normal subjects, and he showed a breakdown of stimulus control at delays somewhere between 30 and 60 seconds. PRISKO did not present discrimination gradients.

The data on the matching of three-letter combinations (Fig. 3) are consistent with the conjecture that an absence of verbal coding was responsible for the relatively short retention of the sample ellipses. H.M. easily worked the delay period up to 40 sec. Unlike ellipses, the trigrams, being composed of familiar letters of the alphabet, provide their own verbal code. H.M. was presumably able to take advantage of the given coding (he was actually observed to form the sounds with his lips), because he did not have to devise his own.

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Résumé—On présente quelques données comportementales additionnelles concernant un malade ayant subi une résection bilatérale de la partie interne des lobes temporaux. Lorsqu'on interrompait brièvement un test de discrimination visuelle, le sujet était incapable de décrire exactement ce qu'il avait vu, malgré celà les performances ultérieures étaient quantitativement similaires aux précédentes. Lorsqu'il s'agissait de matériel verbal, la performance d'appariement à l'exemple proposé n'était pas troublée même avec un délai de 40 secondes, c'est-à-dire après le plus long délai testé. Avec du matériel non verbal qui nécessitait que le malade invente son propre codage verbal, les stimuli présentés comme exemple n'avaient plus d'effet de contrôle sur le comportement s'ils étaient différés de 24–32 secondes. On suggère que cet échec dans l'utilisation du codage verbal joue un rôle important en interdisant l'extension du champ d'appréhension de memoire immédiate.

Zusammenfassung—Der Bericht befasst sich mit zusätzlichen Angaben über das Verhalten eines gut dokumentierten Patienten, bei dem eine bilaterale, mediale Temporallappenresektion durchgeführt worden war. Nachdem man ihn während eines visuellen Diskriminationstestes kurz unterbrochen hatte, war es dem Patienten unmöglich, genau zu beschreiben, was er gerade getan hatte; doch waren seine darauffolgenden Leistungen den vorangegangenen quantitativ ähnlich. Bei verbalem Material zeigte sich seine verzögerte "matching-to-sample" Leistung bis zu 40 Sek., der längsten geprüften Verzögerung, unbeeinträchtigt. Bei nicht-verbalem Material, das den Patienten dazu zwang, seine eigene Verbalkodierung aufzustellen, hatten die als Beispiele gebrauchten Stimuli, nach einer Verzögerung von 24–32 Sekunden, ihre Wirkung auf sein Verhalten verloren.

Obwohl andere Faktoren zweifellos zu der Vergesslichkeit des Patienten beitragen, wird vermutet, dass sein Versagen im Gebrauch verbalen Kodierens eine wichtige Rolle dabei spielt, dass sich seine (immediate) Gedächtnisfrist nicht weiter ausdehnen lässt.