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The Nature of Storage Deficits and State-Dependent Retrieval under Marihuana*

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Abstract. To explore the nature of the storage deficit produced by marihuana intoxication and to determine if retrieval is state dependent for this drug, 48 subjects were presented 10–20-word lists before receiving an oral dose of marihuana and another 10 lists following drug administration. Subjects studied half of each set of 10 pre-drug and 10 post-drug lists using an overt fixed-rehearsal procedure and half using their normal covert free-rehearsal procedure. On Day 1 of the experiment an immediate-recall test followed each of the 20 lists presented. The marihuana-induced deficit in immediate-recall performance on Day 1 for free-rehearsal lists was not eliminated when the fixed-rehearsal procedure was used. Thus, marihuana intoxication impaired the storage of information even when overt rehearsal in the drug and no-drug states was equated. Three days later (Day 4) subjects returned, half receiving marihuana (Drug Group) and half receiving placebo (Placebo Group). All subjects were then administered delayed recall, recognition, and order tests on the words presented on Day 1. Delayed recall performance was asymmetrically state dependent, whereas delayed recognition performance was not state dependent.

Key words: Marihuana – Memory Storage – Rehearsal – State-Dependent Learning.

A previous study, examining the effects of marihuana upon word recall and recognition, suggests that storage processes are affected by the drug while retrieval processes are unimpaired (Darley, Tinklenberg, Roth, Hollister and Atkinson, 1973). That study also indicates that retrieval is not state dependent for words originally presented in the no-drug state. The present study was carried out in order to clarify the nature of the storage deficit caused by marihuana and to determine if the retrieval of words learned in the drug state is similarly non-state dependent.

Darley *et al.* (1973) found that items residing in short-term memory (STM) at the time of immediate free-recall testing were recalled nearly as well by drug as by placebo subjects, whereas marihuana reduced

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immediate-recall performance for items retrieved from long-term memory (LTM). They concluded that marihuana did not impair the entering of information into STM but did affect the transfer of information from STM to LTM. Since in the free-recall task this information transfer is largely dependent upon such subject-controlled processes as verbal rehearsal (Atkinson and Shiffrin, 1968; 1971), it may be that intoxicated subjects do not make optimal use of these "control processes". In order to equate verbal processing of to-be-remembered items for drug and placebo subjects we used in this study a variation of Fischler, Rundus, and Atkinson's (1970) fixed-rehearsal procedure. Subjects were required to repeat aloud, following word presentations, a restricted set of the words previously presented. The aim was to focus the subjects' attention upon producing the overt rehearsals and prevent any covert processing that might result in a drug-placebo difference. If the fixed-rehearsal procedure were to produce equivalent drug and placebo recall performance, we would conclude that the marihuana-induced storage deficit already observed probably resulted from inefficient control-process utilization.

Previous studies (Darley *et al.*, 1973; Abel, 1971) indicate that marihuana may not produce state-dependent learning effects (Overton, 1968). In other words, for marihuana optimal retrieval of information may not necessitate reinstating during testing the same drug state that existed during initial learning. However, since Darley *et al.* and Abel only compared drug and placebo recall performance for information learned in the no-drug state, it is possible that the retrieval of information presented during marihuana intoxication is state-dependent. Since such asymmetry in state-dependent retrieval has been observed with other drugs (Barnhart and Abbott, 1967; Berger and Stein, 1969; Gardner, Glick, and Jarvik, 1972), a similar result for marihuana would not be surprising. The present study was designed to permit us to compare drug and placebo retrieval for words that were originally stored in either the drug or no-drug state.

We were also interested in the subjects' intuitions about their performance in remembering words presented in the drug or no-drug states. One way of measuring these intuitions is to ask the subject to indicate in which state (drug or no-drug) a particular test word had been presented, when in fact the word had not been shown. The subject's response might indicate his subjective feeling about the recognizability of words originally studied in the two states. For example, if he felt less able to recognize words which he had attempted to memorize when intoxicated with marihuana, he might be inclined to guess that an unfamiliar word had been presented under the drug.

To summarize the experimental design, subjects were presented a series of 20 lists of 20 words each on the first day of the experiment (Day 1),

each list followed by an immediate-recall test. After 10 lists had been presented all subjects were given marihuana prior to the presentation of the second 10 lists. On alternate lists, both before and after drug intoxication, subjects used either a fixed-rehearsal study procedure or studied the words in their normal covert manner (free-rehearsal procedure). Three days later (Day 4) subjects returned and were immediately assigned to two groups, one which received marihuana and one which received placebo. Delayed free-recall, recognition and order tests were then given for all words studied on Day 1.

Method

The paid volunteer subjects were 48 adult males, age 18 to 35 years, all of whom were casual users of marihuana (not more than once or twice per week). They were asked to refrain from using any drugs starting one week before and continuing throughout the experiment and were required to fast for at least 8 h before drug administration. The subjects were tested in groups of six. Each group was first presented 10 lists of 20 words each, with the words being presented auditorily at a rate of one word every 5 sec. Five of these lists were composed of words drawn from the Thorndike and Lorge (1944) norms with frequencies of occurrence from 10 to 40 per million, and the other five of words selected from the Toronto Word Pool (Darley *et al.*, 1973). Immediately after presentation of each list, subjects were given a free-recall test on the words from that list (immediate recall). The subjects were instructed to write down in any order as many words as they could remember from the list they had just studied; they were allowed 2 min to complete this test.

Immediately following completion of the immediate-recall test on the 10th list each group of six subjects was divided randomly into two groups of three and the subgroups went to separate rooms to receive the drug. Each subject was administered an oral dose of marihuana in the form of a brownie containing NIMH marihuana calibrated to 20 mg of delta-1-tetrahydrocannabinol (THC). This amount is adequate to produce a well-defined clinical syndrome. Following drug administration, communication between subjects was forbidden.

Following a $1^1/_2$ h period during which they rested and performed a short psychomotor test, the results of which are reported elsewhere (Roth, Tinklenberg, Whitaker, Darley, Kopell, and Hollister, 1973), the original group of six subjects was reformed. The subjects were then presented 10 more lists of words, each list followed by an immediate-recall test on that list. The pool of words from which these lists were drawn and the procedure for list presentation and testing were the same as those for the previous 10 lists. There was no overlap between the words used in the two sets of lists.

Of the 20 lists presented, subjects studied half, the odd-numbered lists, using a fixed overt-rehearsal procedure and the other half using a free covert-rehearsal procedure. On free-rehearsal lists subjects were allowed to silently study the words in whatever manner they felt would maximize their recall performance. On fixed-rehearsal lists the group of six subjects was asked to repeat aloud, in unison, certain items in the list following presentation of each list word. When the first word in the list was presented (e.g., Dog) subjects were to repeat that word six times during the 5 sec interval before presentation of the second word (Dog, Dog, Dog, Dog, Dog, Dog). On presentation of the second word (e.g., Cat), subjects repeated that word and the first word in sequence, cycling through the pair of words three times (Cat, Dog; Cat, Dog, Cat, Dog). The procedure continued in this manner with the just-presented word

always spoken first, followed by the immediately preceding word; in each case the pair of words was repeated three times. Preceding presentation of the first and the 11th lists subjects were given a short list in order to practice the fixed-rehearsal procedure. All subjects were able to use the procedure properly both before and after drug ingestion.

The subjects returned three days later (Day 4). Half of the subjects, randomly chosen, received a brownie containing 20 mg THC and half received a placebo brownie identical in taste and appearance to the marihuana brownie. Each group of six subjects was again divided into sub-groups of three. Drug or placebo was administered under double-blind conditions at the same time of day as the drug was ingested on Day 1. No sub-group of three consisted entirely of drug or placebo subjects. The subjects had been told prior to the experiment that when marihuana was administered it would be in varying doses, ranging from low to moderate strength; thus, all subjects had expectations of experiencing drug effects.

After a $1^1/_2$ h rest and psychomotor-testing period, subjects completed three types of delayed tests:

1. A delayed free-recall test was given first. Subjects wrote in 30 min as many words as they could remember from the 20 lists presented on Day 1.

2. A 400-item, three-alternative, forced-choice recognition test (delayed recognition test) was then administered. Each item consisted of three randomly ordered words including one word from one of the lists presented on Day 1 and two words which had not been on the lists. For each item the subjects were instructed to circle the word they had seen on Day 1. The were allowed 50 min to complete this test.

3. A delayed order test was administered last. It consisted of a randomly ordered list of 250 words, 100 drawn from the lists presented before drug administration on Day 1, 100 from lists after drug ingestion and 50 which the subjects had not seen during the experiment. Subjects were not informed that the test included distractor words. They were instructed to indicate beside every word whether it had been presented before or after drug administration and to make a guess if they were not sure. Subjects were required to complete the delayed order test in 30 min.

The subjects had not been informed previously that any of the three delayed tests would be given. The schema of the experiment is shown in Table 1.

Table 1. Sequence of experimental procedures, Day 1 and Day 4

Elapsed time since drug administration	Experimental procedures
Day 1	Presentation and Immediate Recall of first 10 lists.
	Drug Administration — All Subjects Received Marihuana
1—1/2 h	Presentation and Immediate Recall of second 10 lists
Day 4	
	Drug Administration — Subjects Received Marihuana or Placebo
1—1/2 h	Delayed Recall Test
2 h	Delayed Recognition Test
2—5/6 h	Delayed Order Test

Note—Elapsed times indicate the number of hours from drug administration to the beginning of each procedure.

Results and Discussion

Data from eight of the original 48 subjects are omitted from the results presented here because of absence on the second day of testing or failure to complete the testing procedure in the prescribed manner. Slight deviations from the usual procedure of assigning an equal number of subjects from each group of six to drug or placebo conditions prior to Day 4 testing allowed us to maintain equal sample sizes. Of the 40 remaining subjects, 20 were in the drug group (i.e., they received drug on Day 4) and 20 in the placebo group.

Since the subjects were assigned at random to drug and placebo groups three days after initial list presentation and immediate-recall testing occurred, there was no reason to expect the Day 1 performance of these drug and placebo groups to differ. The data for overall immediate-recall performance confirm the expected equivalence of the groups for both Day 1 pre-drug [drug group = 0.478, placebo group = 0.475, F (1,38) < 1] and Day 1 post-drug lists [drug group = 0.365, placebo group = 0.355, F (1,38) < 1]. The interactions of Drug Group with the factors Type of Rehearsal Procedure and Serial Position are also insignificant. Therefore, additional analyses of immediate-recall performance were carried out after pooling the data from drug and placebo subjects.

The difference in immediate-recall scores between lists presented before drug (0.476) and those presented after (0.360) is in the same direction as the difference found by Darley *et al.* (1973) between placebo and drug subjects. Comparison across drug states must be made with caution in the present study, since drug state is confounded with order of list presentation. However, when immediate-recall performance was explicitly examined over a series of word lists (Keppel and Mallory, 1969; Dallet, 1963), the results indicated that overall recall performance neither increases nor decreases significantly across lists. The implication is that in the present experiment the decline in recall performance may be due largely to drug state.

Another interesting feature of the immediate-recall data is the interaction between drug state and rehearsal procedure. The rationale for introducing the rehearsal-procedure factor was that the expected deficit in immediate recall due to drug intoxication might be reduced or even eliminated for a fixed-rehearsal procedure; if such a reduction or elimination occurred, it would suggest that controlling subjects' strategies for studying the word lists is enough to counteract drug effects. Of course for the fixed procedure to be effective, it must eliminate the opportunity for subjects to engage in covert rehearsal. The data presented in Fig. 1 show that such rehearsal is controlled.

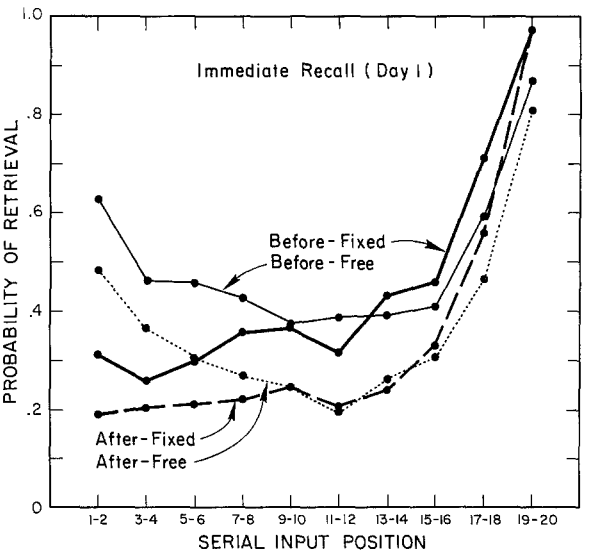

Fig.1. The probability of immediate recall on Day 1 as a function of serial input position. Separate functions are plotted for lists presented before or after drug administration for which either fixed- or free-rehearsal study procedures were used. Data is from all 40 subjects

Plotted here is the probability of an item being correctly recalled on the immediate recall test, as a function of its position of presentation in a list. Separate serial position curves are plotted for items from lists presented before and after drug administration, using either fixed- or free-rehearsal procedures. The free-rehearsal curves have the U-shape typical of most immediate free-recall data. The probability of an item being recalled on the immediate test may be thought of as a composite of the probabilities of its retrieval from STM and LTM (Atkinson and Shiffrin, 1968, 1971). Items at the end of the lists are recalled best (recency effect) since they reside in STM at the time of the test. Other items are retrieved from LTM with early list-items having a higher probability of recall than items from the middle of the list. This primacy effect is assumed to be due to the greater amount of processing the early items receive. Early in the list a subject's limited rehearsal capacity need only be shared by a few items, compared with the relatively large number of items the subject must attempt to maintain during the presentation of middle list-items. It is evident that requiring to subjects engage in the fixed-rehearsal scheme radically alters the shape of the serial position curve. The two fixed-rehearsal curves show the recency effect, but not the primacy effect. We had expected that an effective fixed-rehearsal procedure would

yield this result since all items (except the first and last) received the same number of rehearsals. Pooling across serial positions, there were significant differences in probability of recall between fixed- and free-rehearsal list items, both before drug [free = 0.501, fixed = 0.451, $F(1,38) = 13.33$, $P < 0.01$] and after drug [free = 0.379, fixed = 0.341, $F(1,38) = 8.07$, $P < 0.01$]. These deficits are entirely accounted for by the absence of the primacy effect since the recency portions of the fixed-rehearsal curves are actually somewhat higher than those of the free-rehearsal curves. This cross-over in the fixed- and free-rehearsal curves probably results from the high probability that for the fixed procedure only terminal items reside in STM at the time of the test. In the free procedure terminal items could have been dropped from STM in favor of earlier items (Shiffler *et al.*, 1970).

As suggested earlier, a drug-induced deficit in performance for the free-rehearsal procedure might be reduced or eliminated when a fixed-rehearsal procedure is used. However, as is apparent in Fig. 1, the difference in level of performance between the two fixed-rehearsalcurves is virtually the same as that between the two free-rehearsal curves. Pooling across serial positions, the differences between before- and after-drug curves is 0.12 for the free- and 0.11 for the fixed-rehearsal lists. Although the confounding of drug state with order of list presentation limits interpretation of the nearly equivalent reduction in performance for the fixed and free procedures, it is clear that manipulating subjects' rehearsal strategies does not erase deficits in immediate-recall performance due to marihuana intoxication.

Fig. 2 presents serial-position curves for Day 4 delayed recall and recognition for words from lists presented before drug administration on Day 1. Separate curves are plotted for each type of test, both for subjects intoxicated with marihuana and for those who received placebo on Day 4. Data from fixed- and free-rehearsal lists are pooled since Rehearsal Procedure was not a significant factor in delayed-test performance. The absence of a rehearsal-procedure effect was somewhat surprising since the effect was so substantial for immediate recall, particularly for the primacy portion of the serial-position curves. However, the low level of performance for both delayed recall and recognition may account for the equivalent performance on free- and fixed-rehearsal lists. Another peculiar feature of the recall and recognition curves is the absence of the primacy effect. A delay in testing insures that retrieval is from LTM, so it is not surprising that the recency effect disappears; however, primacy is usually present for delayed tests (Glanzer and Cunitz, 1966; Craik, 1970). In the present experiment the fixed- and free-rehearsal curves combine to form virtually flat curves for both drug and placebo subjects.

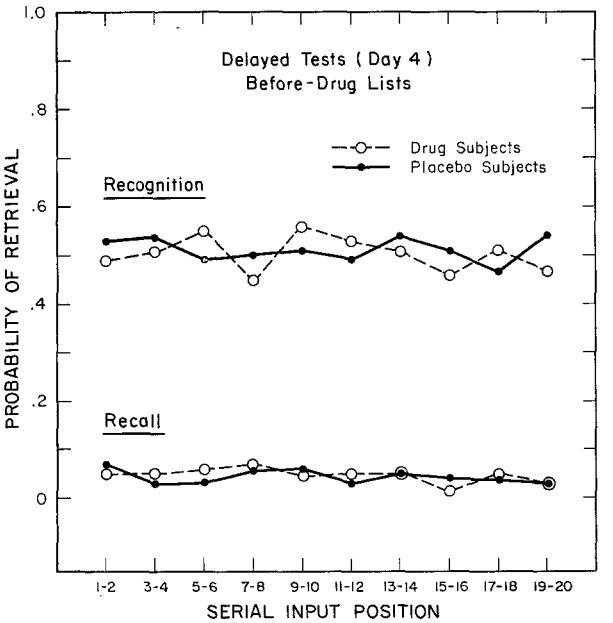

Fig. 2. The probability of delayed recall and recognition on Day 4 as functions of the serial input position of items from pre-drug lists on Day 1. Separate functions are plotted for drug and placebo groups

The absence of primacy for fixed-rehearsal curves is understandable since there was no primacy in immediate recall, but the similar shape of free-rehearsal curves, verified by the insignificant Rehearsal Procedure $\times$Serial Position interaction for all delayed tests, is less easily explained. It may be that the flatness of the curves is again the result of low performance levels.

Since the data presented in Fig. 2 represent drug and placebo subjects' performance on words learned in the no-drug state, they are comparable to the data obtained by Darley *et al.* (1973) and Abel (1971). In the present experiment subjects tested on Day 4 under drug and those tested under placebo did not differ on either delayed recall [placebo = 0.046, drug = 0.049, F (1,38) < 1] or delayed recognition [placebo = 0.503, drug = 0.502, F (1,38) < 1]. These findings replicate those of Darley *et al.* in all respects and those of Abel with regard to delayed recall. The finding that marihuana intoxication does not interfere with retrieval processes is thus confirmed. In addition, state-dependent effects are not present in delayed recall or recognition for items learned in the no-drug state.

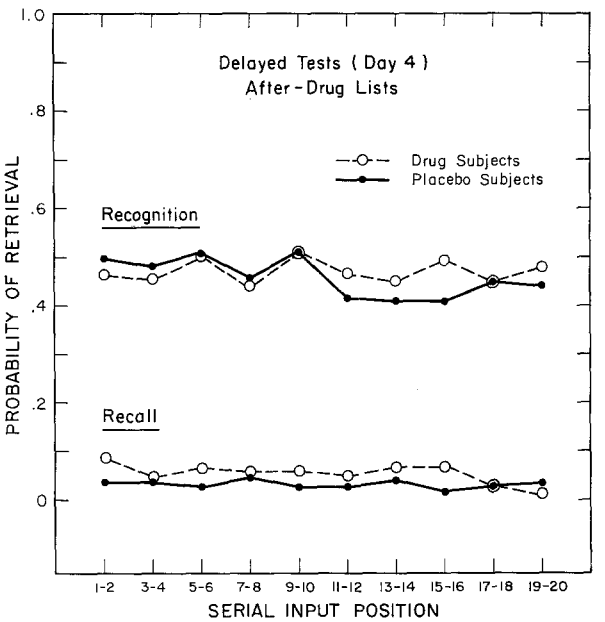

Fig. 3. The probability of delayed recall and recognition on Day 4 as functions of the serial input position of items from post-drug lists on Day 1. Separate functions are plotted for drug and placebo subjects

Delayed-test performance for words learned in the drug state on Day 1 shows a different pattern. In Fig. 3 serial-position curves are plotted for drug and placebo subjects' recall and recognition performance. Again, Rehearsal Procedure is not a significant factor and serial-position trends are negligible. However, Day 4 drug state is important in this case since the delayed-recall performance of drug subjects (0.056) significantly surpasses that of placebo subjects (0.033) [F (1,38) = 0.573, $P < 0.05$]. This result may be interpreted as an indication that for items learned during marihuana intoxication, *recall* is state dependent. Since, as indicated in Fig. 2, no state dependency resulted for material presented in the no-drug state, state dependency appears to be assymmetrical for marihuana.

An interesting and puzzling additional finding is that the Day 4 *recognition* of words learned after drug administration on Day 1 is not state dependent. The drug subjects' performance on those words (0.473) did not differ significantly from placebo subjects' performance (0.459) [F(1,38) < 1]. One possible explanation of the different results for recall and recognition testing is that the emergence of dissociation effects depends on both the type of initial learning task and the subsequent retesting pro-

cedure. If this is a valid hypothesis, then certain paradoxical results in the literature might be explicable. For example, Rickles, Cohen, Whitaker, and McIntyre (1973) found retrieval to be symmetrically state dependent for marihuana, but their subjects performed a paired-associate learning task which may involve different storage and retrieval processes than the tasks used in the present experiment. Goodwin, Powell, Bremer, Hoine, and Stern (1969) examined subjects' performance on a variety of memory tasks in order to assess the state-dependent effects of alcohol. Sentence-memory and word-association tasks showed state dependency, while a picture-recognition task did not. Thus, in drawing conclusions about the effects of drug state upon memory retrieval or any memory process, consideration must be given to the nature of the experimental task.

Results from the order test (in which subjects were to identify whether a particular word had occurred before or after drug administration on Day 1) showed no significant effects for the factors Drug-Group or Rehearsal Procedure, both for words learned before and after drug administration. This indicates that drug and placebo subjects were equally able to establish when a particular word had been presented on Day 1. Also no difference existed between groups with regard to the judgment of when distractor words (which subjects had not seen earlier) were presented. Both groups judged that approximately half these words had occurred before drug on Day 1 and half after drug. Thus it appears that subjects did not have intuitions about the unequal recognizability of words presented in different drug states, or, if they did, the intuitions were not used in deciding when unremembered words had been presented.

The purpose of the present study was to examine the effect of marihuana upon memory storage and retrieval. With regard to storage processes, the important finding is that even when required to use a rigid, automatic approach to list-learning (such as the fixed-rehearsal scheme) subjects do better in the no-drug than in the drug condition. In other words, even though overt rehearsal processes were equated in the no-drug and drug states, the marihuana-induced storage deficit did not disappear.

The use of the concept of asymmetric state dependency has been called into question (Deutsch and Roll, 1973). However, we consider the idea that material learned in the drug state is most accessible in the same state to be a parsimonious and intuitively reasonable explanation of our delayed-recall data, particularly since drug users commonly report that events experienced while intoxicated are not remembered until the drug is ingested again at a later time.

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