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Marijuana: An Analysis of Storage and Retrieval Deficits in Memory With the Technique of Restricted Reminding[1,2]

LOREN MILLER, TERESA CORNETT AND DENNIS MCFARLAND

Veterans Administration Hospital, Cooper Drive Division, Lexington, KY 40507

Department of Psychiatry, University of Kentucky Medical Center, Lexington, KY 40506

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MILLER, L., T. CORNETT AND D. McFARLAND. *Marijuana: an analysis of storage and retrieval deficits in memory with the technique of restricted reminding.* PHARMAC. BIOCHEM. BEHAV. 8(4) 327–332, 1978. – A simple word list learning technique which has previously been shown to be useful clinically in evaluating disordered memory in organic patients, was employed to assess the effects of marijuana on storage and retrieval processes in memory. Twelve male subjects were administered marijuana and placebo in two separate sessions separated by a one week interval. Each subject served as his own drug control. Fifteen min after smoking a 500 mg marijuana cigarette containing 2.1% Δ^9–THC or a placebo cigarette, each subject was presented with a 30-item word list and then required to recall it in writing. Half of the subjects in the first session recalled one list while the other half recalled a second similarly constructed list. The lists were reversed during the second session. Following the initial recall test, only those words not recalled were presented again. Presentation of a given word continued only until an item was recalled once. There were 12 recall trials. This method termed restricted reminding allows for the simultaneous evaluation of storage and retrieval without confounding due to continuous presentation. The critical data were the number of items recalled without presentation following initial recall. Results indicated that marijuana produced a slower rate of acquisition of items into storage in comparison to placebo although the same number of items were eventually stored under both conditions. The drug appeared to exert its most deleterious effect on the retrieval of information from long term storage.

Marijuana Free recall Restricted reminding Storage Retrieval

A NUMBER of investigators have concentrated on assessing the effects of marijuana on various aspects of the memory process [1, 7, 8, 9, 10, 11, 12, 13, 14]. This area of study has been amenable to exploration largely because of the work of cognitive psychologists who have developed models of memory which are highly quantifiable. Based on the memory model proposed by Shiffrin and Atkinson [15], three studies have proposed that marijuana exerts its deleterious action on memory by inhibiting the passage of information from short term to long term storage. Once information passes into long term memory, marijuana-recall deficits are not noted. This suggests that the drug affects storage rather than retrieval processes [1,9]. However, another study by the present authors indicated that recall of prose material learned in a drug or non-drugged state was reduced following intoxication 24 hr later [13]. Thus, in some instances retrieval processes may be influenced by marijuana. Klonoff *et al.* [10] also have suggested that output from memory is influenced by marijuana, while the acquisition process is left largely intact.

Conclusions regarding the effect of marijuana on memory have been based largely on free recall verbal learning studies. In a free recall paradigm, lists of items are repeatedly presented with recall occurring after each presentation. Buschke [3,4] has argued that evaluating disordered memory in this fashion obscures the analysis of retrieval of information from long term memory because of interference produced by the immediate recall of items which were recently presented. Storage and retrieval processes cannot be evaluated when all items are presented before every recall attempt, because immediate recall of an items does not demonstrate that the item resided in long term memory. According to Buschke [3] an item can be considered to be in long term memory only when it is recalled without repeated presentation.

In an effort to evaluate the effect of marijuana on storage, retention and retrieval processes simultaneously, the present study utilized the technique of restricted reminding proposed by Buschke [3,4]. With this technique an individual is asked to recall a list of words that have just

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[2] Thanks is expressed by Dr. Herman Buschke for his personal description and insightful discussion of the restricted reminding technique.

been presented to him. Following this initial presentation and recall, only those words not recalled are presented on the following trial. Presentations continue until each word has been recalled at least once and once a word is recalled, it is never presented again. However, an S attempts to recall all the words in the list on each trial.

Encoding of a word is said to have taken place when a word is recalled providing that it has not been presented on the previous trial, and is assumed to have occurred on or before its first recall even though there is no evidence of this process until the word is spontaneously recalled a second time. Long term storage (LTS) represents the cumulative number of encoded items on a given trial, while retrieval consists of the number of words recalled on each trial that are considered to be in LTS.

METHOD

Subjects

Twelve male volunteers who were experienced users of marijuana served as subjects in this experiment. All were considered light to moderate smokers of marijuana with use varying from 2–4 times per week to a few times per month. All ranged in age from 21 to 30 years and each was paid for participating. Prior to the study, all subjects were screened for mental and physical health employing a brief interview, MMPI, physical examination and a series of laboratory tests including a liver function test, urinalysis and electrocardiogram. All were asked to refrain from smoking marijuana for four days prior to testing which took place on two separate occasions separated by a week. Half of the subjects were administered marijuana in the first testing session followed by placebo in the second session, while the reverse occurred for the other half.

Procedure

Upon arrival in the laboratory, subjects were assigned randomly to a marijuana (M) or placebo (P) condition. Prior to smoking they were told that they would be participating in an experiment which would test their ability to remember words. Fifteen min after smoking the experimenter read a list of words 30 items in length to a subject at the rate of one word every 3 sec. As soon as the entire list was presented, the subject was required to write down all the worlds that he could remember. Following each recall test, the experimenter checked the written responses for their accuracy. Only those words not recalled were repeated to the subject on the next trial. List presentations continued until each word was recalled at least once so that by Trials 5 to 6, words were no longer being presented. Recall testing continued for 12 trials. All subjects were run individually and testing was completed in a quiet comfortable room. A scheme of experimental procedures is presented in Table 1.

Drug Administration

Marijuana cigarettes obtained from the National Institute on Drug Abuse were employed in this study. Subjects smoked a single 500 mg cigarette containing 2.1% Δ^9–THC or a placebo cigarette from which all THC had been extracted. They were allowed to smoke in any manner they desired but were instructed to consume as much of the butt as possible. Smoking took between 7 and 10 min. Pulse rate measures were taken before smoking, at the end of smoking, 15 min after smoking and at the end of the session. At the completion of testing, each subject rated the intensity of his high (potency) and its pleasantness on a 0–100 point scale.

Stimulus Materials

The stimulus materials consisted of two similarly constructed 30-item word lists consisting of common objects. The words were drawn from the Thorndike-Lorge norms [16] and had a frequency of occurrence in the English language of 100 or more per million words.

RESULTS

Pulse Rate

A significant overall increase in pulse rate occurred following intoxication with M in comparison to P, $F(1,11)$

TABLE 1

SCHEME OF THE EXPERIMENTAL PROCEDURES

Elapsed Time Since Completion of Smoking	
	Ten Min Rest Period
	Instructions
	presentation of practice list
	pulse rate measure
	drug or placebo administration
1 min	pulse rate measure
15 min	pulse rate measure
20 min	presentation of word list and recall trials
60 min	potency and pleasantness ratings
65 min	pulse rate measure

= 25.71, $p<0.0006$. Pulse rate changed over successive measurements, $F(3,33) = 60.54$, $p<0.0001$. Newman-Keuls multiple comparison tests indicated that pulse rate was significantly elevated immediately ($p<0.01$) and 15 min ($p<0.01$) following smoking (a rise to approximately 90 beats per min). At 65 min, pulse rate values began to return to baseline. Following P, pulse rate remained unchanged across successive measurements. These results confirm previous studies finding an elevation in pulse rate following intoxication with M [5].

Potency and Pleasantness Ratings

Smoking materials containing the active Δ^9-THC were rated as being more potent than P, $F(1,11) = 24.56$, $p<0.0007$. The experience was also rated as being more pleasant following M smoking, $F(1,11) = 9.71$, $p<0.01$. The mean potency and pleasantness ratings for the M condition were 63.33 and 63.91 and for the P condition 23.33 and 31.00, respectively.

Restricted Reminding

Figure 1 shows the recall performance of the 12 subjects under both M and P. Following M intoxication, it took significantly more trials (4.58 ± 0.80 vs 3.75 ± 0.75) to initially recall all items at least once, t [11] = 3.55, $p<0.005$. When an item is spontaneously recalled without being presented again following initial recall, it is assumed to have been encoded in long term storage (LTS) on or before the trial on which it was presented. Thus, an item recalled following presentation on a given trial is not considered to be in LTS until it is recalled again on a subsequent trial. The LTS curve represents the cumulative number of items encoded on each trial. A drug condition × recall trials analysis of variance indicated that an equivalent number of items (approximately 23/30 words) were stored under both M and P. Recall increased over trials, $F(1,121) = 194.22$, $p<0.0001$ and drug condition interacted significantly with trials, $F(11,121) = 5.47$, $p<0.0001$. Even though performance was inferior under M on all recall trials, Newman-Keuls tests indicated that none of the comparisons reached significance.

The total number of items retrieved from LTS increased under both treatment conditions even though word presentations completely ceased after trial 6, $F(10,110) = 94.16$, $p<0.0001$. A greater number of items retained in storage were retrieved following P in comparison to M, $F(1,11) = 5.70$, $p<0.03$. The interaction of drug condition and recall trials was also significant, $F(10,110) = 3.26$, $p<0.001$. Newman-Keuls tests indicated that on trials 3–8, M produced significantly inferior retrieval in comparison to P ($p<0.05$ for all trials) but by Trial 9, the differences were nonsignificant although the P condition retained its superiority. A subsequent analysis indicated that when retrieval was expressed as a percentage of number of items in LTS, the retrieval deficits remained as pronounced as in the former analysis.

The characteristic which most distinguished performance under M in contrast to P was the inconsistency with which words were recalled under drug. That is, M produced significantly more memory lapses or recall failures during the retrieval of items from LTS. For example, under M, an encoded word might be retrieved on a given trial following which a 3 to 4 trial lapse in recall would occur before the word would be recalled again. Since items were spontaneously recalled after many recall failures, it cannot be concluded that the intoxicated subject lost information from storage when he failed to retrieve. In fact, overall storage during intoxication was as good as under P, albeit slower. These retrieval lapses or recall failures are expressed graphically in the cumulative recall failure curves in Fig. 1. A drug condition × recall trials analysis of variance indicated that following M significantly more recall failures occurred, $F(1,11) = 20.52$, $p<0.001$. Neither the trials effect nor the drug condition × trials interaction reached significance.

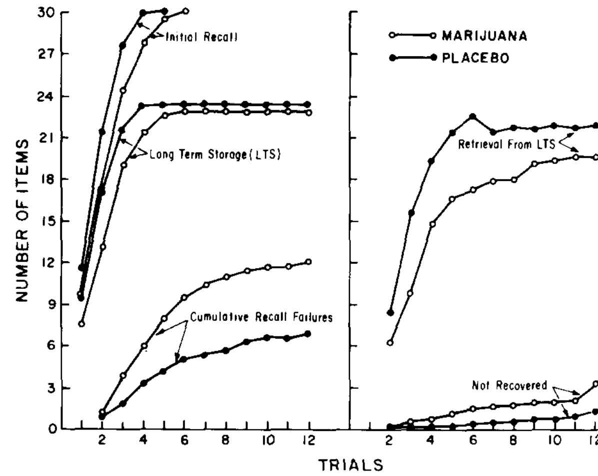

FIG. 1. Analysis of free recall by restricted reminding for P and M conditions: Initial recall, LTS, retrieval from LTS, cumulative recall failures, and number of items not recovered from LTS.

Although, most items in LTS were eventually retrieved, some were not. While this number was quite low in both groups, in the M condition, significantly more items were not recovered in comparison to the P condition (3.25 ± 0.31 vs 1.41 ± 0.28), $F(1,11) = 6.45$, $p<0.03$. The number of items not recovered increased over trials, $F(10,110) = 14.29$, $p<0.0001$). The interaction of drug condition and recall trials also reached significance, $F(10.110) = 2.67$, $p<0.007$. Newman-Keuls tests indicated that on trials 5–6 and 8–12 more items were lost from LTS during the period of intoxication ($p<0.05$ for all comparisons).

The consistency with which an individual retrieves information from LTS can be determined by analyzing two retrieval components, initial list consistent retrieval (ILCR) and additional list learning (AL). ILCR refers to those items retrieved from LTS consistently from the trial on which recall first took place. Thus, if an item was recalled for the first time on a given trial, and then recalled on all subsequent trials it was said to be consistently retrieved. AL refers to those items which were consistently recalled eventually after having been recalled inconsistently for a number of preceding trials. It can be seen from Fig. 2 that a greater proportion of total recall was due to ILCR in the P condition in comparison to the M condition $F = (1,11) = 6.94$, $p<0.02$). ILCR increased over trials, $F(10,110) = 2.06$, $p<0.03$). Newman-Keuls multiple comparison tests indicate that ILCR was similar in both groups on Trial 2 but that the P group obtained superiority by Trial 3 with performance remaining superior throughout acquisition ($p<0.05$ for all other trials). AL was marginally superior in the M condition, $F(1,11) = 4.16$, $p<0.06$ and increased over

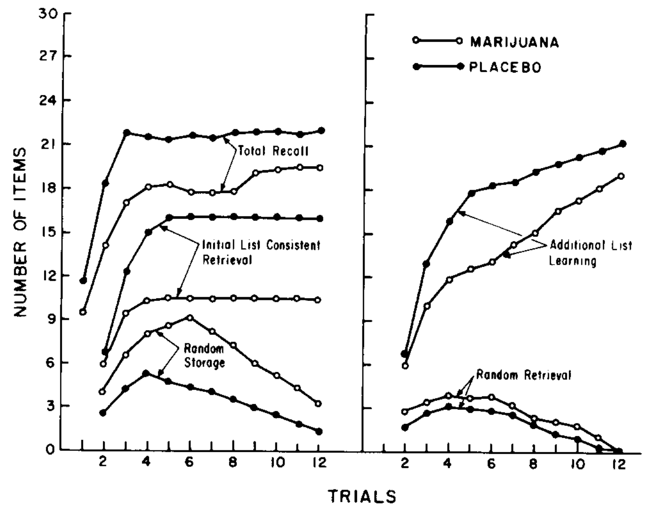

FIG. 2. Analysis of free recall by restricted reminding for P and M conditions: total recall, additional list learning, initial list consistent retrieval, random storage, random retrieval.

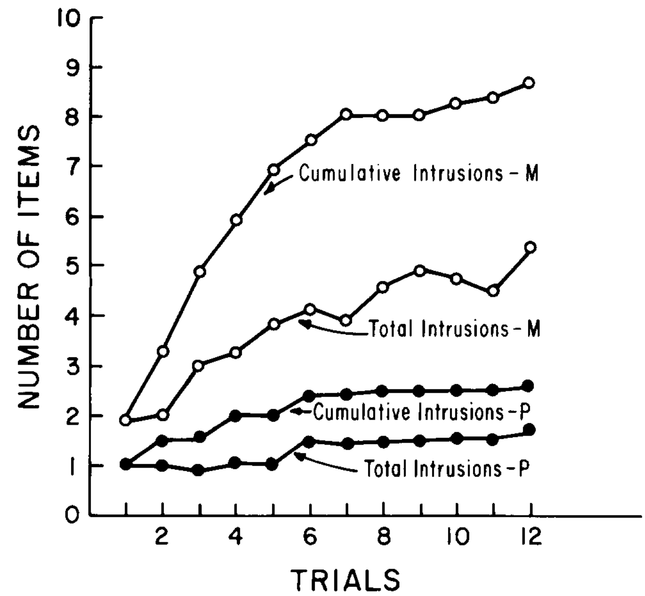

FIG. 3. Total number of intrusion errors and cumulative intrusion errors for P and M conditions.

trials in both treatment conditions, $F(10,110) = 45.26$, $p<0.0001$. The drug condition by trials interaction also reached significance, $F(10,110) = 4.26$, $p<0.0001$. On the last four acquisition trials AL was superior in the M condition ($p<0.01$ in all cases). This superiority occurred because more items were available in random storage under drug, $F(1,11) = 7.12$, $p<0.02$. Random storage consists of those items in LTS that are not yet consistently retrieved. Random storage changed over trials, $F(10,110) = 15.03$, $p<0.0001$, with drug condition interacting with trials, $F(10,110) = 2.09$, $p<0.03$. Initially, random storage increased at a faster rate for intoxicated subjects but the difference between M and P conditions in numbe- of items available in the random store decreased as recall trials continued. Newman-Keuls tests indicated that more items were in random storage on Trials 3–7 in the M condition ($p<0.05$ on Trials 4 and 7 and $p<0.01$ on Trials 3, 5 and 6). This means that items in random storage were eventually becoming consistently recalled in the M condition (as reflected in the AL curve).

No differences existed between the P and M conditions with regard to random retrieval which consists of items retrieved from random storage. Random retrieval changed over trials with the number of items retrieved from random storage declining with repeated recall, $F(10,110) = 10.54$, $p<0.0001$. The interaction of drug condition and recall trials did not reach significance. Buschke [3] has shown that the probability of retrieving an item from LTS does not increase prior to the onset of consistent retrieval.

One interesting aspect of these data concerns the intrusion error rates under the drug condition. Intrusion errors consist of the introduction of extralist words during recall. In Fig. 3 intrusions are expressed in two ways (1) total intrusions – which consisted of the total number of intrusions made and include a given word as an intrusion error each time it was repeated. For example, a subject could introduce an extralist word and repeat it on consecutive trials. On each of those trials it was counted as a separate error. (2) Cumulative intrusions – which consisted of the number of different intrusions which were emitted. It can be seen that M elevated the total number of intrusions, $F(1,11) = 15.62$, $p<0.003$ and that intrusions increased over trials, $F(11,121) = 6.53$, $p<0.0001$. The interaction of drug condition and recall trials was significant, $F(11,121) = 4.04$, $p<0.0001$. The total number of external intrusions remained relatively constant from trial to trial in the P condition but showed a gradual increase over trials under M. Newman-Keuls tests indicated that intrusion errors increased significantly on trials 3–12 ($p<0.05$ on Trials 3–4 and $p<0.01$ on Trials 5–12). The number of different intrusions increased following intoxication, $F(1.11) = 17.62$, $p<0.002$ and over trials for both treatment conditions, $F(11,121) = 15.29$, $p<0.0001$. The drug condition × trials interaction was also significant, $F(11,121) = 10.35$, $p<0.0001$. Newman-Keuls tests indicated that the number of different intrusion errors were significantly elevated on Trials 4–12 ($p<0.05$ for all trials).

DISCUSSION

The present study employed the technique of restricted reminding to evaluate the effect of M on storage and retrieval processes in memory. Unlike the usual free recall paradigm, word presentations were limited to presentation until recall occurred once. Recall without presentation after an initial recall was considered to be an estimate of retrieval from long term storage on each trial while storage was determined by calculating the number of items ever recalled following the termination of presentation.

Under both M and P, about 75% of the items presented were both stored and eventually retrieved. The spontaneous recovery of items after retrieval failure indicated that items were stored just about as well following M as under P. The distinguishing characteristics which differentiated M and P conditions were the intermittent lapses in retrieval which occurred during the intoxicated state and the highly consistent recall in the P state from the initial recall on.

Buschke [3] has suggested that retrieval of information from LTS can be analyzed best by postulating a two stage learning model. The first stage termed item learning is characterized by inconsistent retrieval while the second stage, list learning, is characterized by consistent retrieval.

When an item of information is consistently retrieved it is considered to have been learned as part of a list or integrated with the retrieval of other items in the list. List learning involves retrieving a larger and larger group of items without retrieval failure. Items are retained in storage under M (as indicated by random storage) and are available for subsequent retrieval but are not as effectively processed and integrated with other items as occurs in the non-drug state.

Previous studies have suggested that M affects storage rather than retrieval processes in memory [1, 8, 9]. However, the present study also suggested that retrieval from long term storage is reduced by M. The apparent discrepancy in the results of previous studies and this one may be partly attributable to methodological and theoretical considerations rather than to empirical differences. Previous studies have interpreted the memory deficit found under M in terms of two factor memory theory. It has been suggested that the major effect of the drug is to retard the passage of information from short term to long term storage. This hypothesis is based on the finding that the serial position curve, a U shaped function relating probability of recall to serial position of input items, is differentially affected by M. The percentage of words recalled from the early and middle portions of the curve, which reflect output from long term and short term components, respectively, is reduced following intoxication. The most recently presented items are not affected suggesting that information does enter the sensory store.

However, in a recent study in our laboratory [13] on prose recall, the obtained serial position curves following M intoxication, did not directly correspond with those found in previous studies [1, 8, 9] in that the recency portion of the curve was reduced by the drug. This finding as well as the results of the present study may necessitate an alternative explanation of the effects of M on memory.

According to Bushke [3], information is always encoded within a given context. Information about the target word and its relationship to other words in the semantic system provides a basis of organization (i.e., list learning). That is, the learner imposes structure on information to be recalled by employing his own idiosyncratic basis of organization. Effective encoding of information for consistent retrieval requires an individual to change retrieval strategies rapidly and to use semantically related information from permanent storage. M may affect this process. This conception of memory is similar to the levels of processing approach proposed by Craik and Tulving [6]. They hypothesize that differences in level of the initial processing of to-be-remembered material results in different memory codes. Superficial processing induces an acoustic or phonetic memory trace which is transitory or fades rapidly, while "depth" processing results in a semantically encoded memory trace which is more enduring. Therefore, viewing the effect of M on memory in terms of its actions on an individual's ability to integrate a given item of information with respect to present and past memory structure, may be more fruitful than an interpretation in terms of storage – retrieval distinctions.

Intrusion errors were elevated and increased over trials in the M condition in comparison to P. This phenomena has been replicated in two studies in our laboratory [12,14] and appears to be a robust effect. Yet, the mechanism by which M produces intrusions as well as what these errors represent have been difficult to determine, especially since there appears to be no systematic relationship between number of intrusion errors made and recall deficits [14].

One possible explanation for the increase in intrusions following intoxication can be found in the generation-recognition model of memory proposed by Anderson and Bower [2]. This model posits that level of recall is a joint function of the effectiveness of self-generated response probes during retrieval which are tested for list membership and the degree of integration of memory traces against which the probes are tested. During intoxication, intrusion errors were characterized in two ways: (1) subjects would commit an intrusion and then encode the error and repeat it on the majority of recall trials and (2) subjects would commit an error and then drop the item from recall and introduce another. The former type of error may again reflect poor integration of memory traces; that is, input items are not easily differentiated from other items in memory following intoxication because the memory trace may be disintegrating at a rapid rate. This may result in the encoding of extraneous word from long term memory. Those intrusions that are committed but not encoded may be self-generated response probes which are easily rejected in the non-intoxicated state but because of poor integration of input items in the drug state, may gain some temporary response strength.

In summary, these results suggest that following intoxication with M in comparison to P the same amount of information can be eventually stored provided repeated recall attempts are allowed. However, intoxication results in poorer retrieval which is characterized by lapses in recall. These lapses may reflect a reduced capacity for integrating material in memory for recall.

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