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Marijuana and Memory Impairment: the Effect of Retrieval Cues on Free Recall[1]

LOREN MILLER[2], TERRY CORNETT, DENNIS BRIGHTWELL, DENNIS MCFARLAND, WILLIAM G. DREW AND ABRAHAM WIKLER

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

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MILLER, L., T. CORNETT, D. BRIGHTWELL, D. MCFARLAND, W. G. DREW AND A. WIKLER. *Marijuana and memory impairment: the effect of retrieval cues on free recall.* PHARMAC. BIOCHEM. BEHAV. 5(6) 639–643, 1976. – In an attempt to ascertain the effect of retrieval cues on recall deficits which occur following intoxication with marijuana, 40 male volunteers were presented with word lists following the smoking of a single one gram marijuana (0.94% Δ^9 -THC) or placebo cigarette and then were required to recall these words immediately after presentation. Recall occurred under a condition in which cues representative of to-be-remembered words were present or in an uncued condition. Results indicated that recall was depressed following marijuana administration under both cued and uncued conditions with cues being only mildly effective in reversing the recall deficit. There was no increase in the number of internal intrusions under marijuana, but the number of external intrusions was significantly elevated under the cued condition.

Marijuana Retrieval cues Recall Intrusions

EARLY investigations of the acute effects of marijuana on the alteration of states of consciousness were replete with descriptions of thought disturbances, as well as perceptual and mood changes [3, 4, 16]. One of the more prominent cognitive distortions reported was a transitory memory loss for recent events. Recent studies employing smoked marijuana or orally ingested Δ^9-tetrahydrocannabinol (Δ^9-THC) have confirmed these original observations [1, 6, 8, 9, 10, 13, 14, 16].

Free recall paradigms have usually been employed in these studies [1, 8, 9, 10, 16] and it has been found that information presented during the intoxication period is less easily recalled than information presented following placebo. Based on the dual process memory model of Shiffrin Atkinson [19], it has been suggested that the major effect of marijuana is to retard the passage of information from short term to long term storage. This hypothesis is supported by 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 marijuana. The percentage of words recalled from the early and middle portions of the curve which reflect output from long term and short term storage mechanisms respectively, is reduced. On the other hand recall of the most recently presented items is not influenced by marijuana [1, 8, 9, 10].

Although these results are compelling, it should be noted that failure to recall an item during a free recall test does not necessarily mean that the trace of the item is no longer available in memory storage, but may simply mean that the item is not accessible [24]. Access to stored information may be dependent on retrieval cues formed during list presentation and utilized during recall. This hypothesis has been confirmed in a series of studies by Tulving and associates [21, 22, 23, 24], who have shown that when cues representative of to-be-remembered words are presented prior to recall, a significantly greater percentage of words are remembered than when these cues are not presented. This suggests that in traditional free recall, more words are actually available in memory than are accessible.

A recent study by Eich *et al.* [12] employing marijuana supports this hypothesis. It was shown that information made inaccessible following a change in drug state was recovered through the use of retrieval cues. More specifically, a group presented with a categorized word list following intoxication recalled fewer words four hours later under placebo (asymmetrical dissociation) than did groups receiving marijuana or placebo on both occasions. However, when category cues representative of the to-be-remembered words were presented prior to recall, this transfer deficit was attenuated.

While the Eich *et al.* [12] results suggest that retrieval cues can reverse impaired recall which occurs as a function of drug state change, it is not known whether cues provided during the period of intoxication would reverse memory deficits produced by marijuana. Therefore, the purpose of the present study is to determine whether material learned following marijuana intoxication might be made accessible

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[2] Requests for reprints should be sent to Loren L. Miller, Department of Psychiatry, University of Kentucky Medical Center, Lexington, Kentucky 40506.

in memory with the use of retrieval cues, even though it does not appear to be available.

METHOD

Subjects

Forty male volunteers who were considered moderate smokers of marijuana (2–4 times per week) were recruited for the study. All Ss ranged in age from 21–28 years and each was paid $15 for participating. Prior to the study, they 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 Ss were asked to refrain from smoking marijuana for four days prior to testing.

Design and Procedures

Upon arrival in the laboratory, Ss were assigned to a marijuana (M) or placebo (P) condition. The groups were roughly equated on the basis of WAIS vocabulary subtest scores. Prior to smoking they were told they would be participating in an experiment which would test their ability to remember words. Taped instructions indicated that they would hear a series of word lists with one word presented every three seconds. Immediately following list presentation, they were required to write down in any order as many words as they could remember. A given list of words was presented three times.

Two lists of 35 words were drawn from Thorndike and Lorge [20] norms, with frequencies of occurrence from 10–40 per million. An answer sheet was provided with the initial letter of each word in the list printed in the order of presentation at the top. These letters served as retrieval cues and have been previously shown to be highly effective in this context [11]. In the cued condition, Ss were told that these cues would be available during presentation of the lists and during the retention test, and could be used in any way they wished in order to help them organize their thoughts for recall. In the uncued condition, the same instructions were given except that Ss were told that the retrieval cues would be removed prior to the recall test. At least 5 minutes was allowed for recalling each list. Prior to smoking, Ss were given sample lists of 10 words each in both cued and uncued conditions. Order of lists and cueing condition were counterbalanced within M and P groups. All experimental procedures are listed in Table 1.

Drug administration. Marijuana cigarettes obtained from the National Institute of Drug Abuse were employed in this study. Subjects smoked a single one gram cigarette containing 0.94% Δ^9-THC (9.4 mg) or a placebo marijuana cigarette from which all THC had been exhausted. A standardized smoking procedure was employed. Following presentation of the sample lists, each participant was presented with a single cigarette, instructed to inhale deeply, hold the smoke in his lungs for 10–15 sec, exhale and then wait 30–45 sec before taking the next puff. Puff inspiration was supervised and timed by the experimenter. Smoking took between 7 and 10 min and Ss were required to smoke as much of the cigarette as possible. All testing was undertaken in a comfortable room and was completed in a single session.

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 S rated the intensity of his high and its pleasantness on a 0–100 point scale.

TABLE 1

SCHEME OF THE EXPERIMENTAL PROCEDURES

Elapsed Time Since Drug Administration	
	Instructions Presentation of practice lists Pulse rate measure Drug or placebo administration
1 min.	Pulse rate measure
15 min.	Pulse rate measure
20 min.	Presentation and immediate recall of cued or uncued lists
40 min.	Presentation and immediate recall of second set of cued or uncued lists
45 min.	Potency and pleasantness ratings
50 min.	Pulse rate measure

RESULTS

Pulse Rate

The mean pulse rate for M and P groups prior to smoking was 69.9 (± 12.63) and 68.8 (± 8.37) beats per minute respectively. Pulse rate values immediately after smoking, 15 min after smoking, and at the end of the session rose to a mean of 99, 94.9 and 76.7 beats per minute respectively for the M group. The corresponding means for P controls were 73.4, 71.7 and 66.55 beats per minute. A dose × time analysis of variance indicated that marijuana significantly increased pulse rate over control values, $F(1,38) = 15.67$, $p<0.008$, and that this increase was dependent on time of measurement, $F(3,114) = 66.63$, $p<0.0001$, with the most prominent changes occurring immediately and 15 min after smoking. This was reflected in the significant dose × time interaction, $F(3,114) = 31.36$, $p<0.0001$. Newman-Keuls multiple comparison tests indicated that pulse rate taken immediately and 15 min following smoking was significantly elevated over control levels ($p<0.01$). The final pulse rate measure was not significantly elevated over baseline. The significant increase in pulse rate is comparable to that found by other investigators [7]. The slight elevation in pulse rate in placebo subjects immediately following smoking has been reported elsewhere [5] and may be a reflection of an emotional response as the S anticipates becoming intoxicated.

Potency and Pleasure Ratings

M subjects rated their smoking material as being more potent, (t (38) = 8.30 $p<0.0001$), and the experience more pleasant (t (38) = 3.16, $p<0.003$), than controls. The mean ratings for the drug Ss were 67.5 (± 18.20) and 65 (± 19.33) for potency and pleasantness respectively, while P controls gave mean values of 28 (± 11.46) and 47 (± 17.21). For M Ss, potency and pleasure ratings were significantly correlated with each other (r (18) = 0.60, $p<0.005$), but

neither of these variables was significantly correlated with total recall of words or changes in pulse rate at any time interval. In the P group, the correlation between pleasure and potency ratings was not significant.

Cued vs Uncued Recall

A three way analysis of variance (cued versus uncued recall; M versus P; recall over successive lists) was performed for number of recalled words. Significant main effects were found for the drug variable with M producing inferior recall in comparison to P, $F(1,38) = 11.26$, $p<0.002$, and the cued variable with cued recall being superior to uncued recall, $F(1,38) = 20.19$, $p<0.0002$. Also, recall improved significantly across list presentations, $F(2,76) = 353.55$, $p<0.0001$.

Drug condition interacted with the cue variable producing marginal significance, $F(1,38) = 3.79$, $p<0.06$. The mean number of words recalled across the three lists by each group were as follows: P cued 67.10 (± 19.6); P uncued 54.45 (± 16.9); M cued 46.35 (± 15.9); M uncued 41.35(± 15.8). Newman-Keuls multiple comparison tests indicated that the difference between the cued and uncued means both reached significance, ($p < 0.01$) and ($p < 0.05$) respectively. Also the P group recalled significantly more words under cued than uncued conditions, ($p < 0.05$). This comparison did not reach significance in the M group. The two-way interactions of drug condition and list presentation and cue condition and list presentation were both highly significant, $F(2,76) = 5.29$ and $F(2,76) = 5.30$, both ($p<0.007$). These interactions are presented in Fig. 1. Not only was recall higher following each list presentation under P in comparison to M and following cues in comparison to their absence, but an analysis of orthogonal trends indicated that the linear slopes differed for P and M groups, $F(1,38) = 6.77$, $p< 0.01$, and for the cued and uncued condition, $F(1,38) = 6.39$, $p< 0.02$. Rate of list acquisition was more pronounced in the P and cued conditions.

Although the triple interaction of drug, cue and list condition did not reach significance, an examination of the cell means comprising this interaction suggested that a

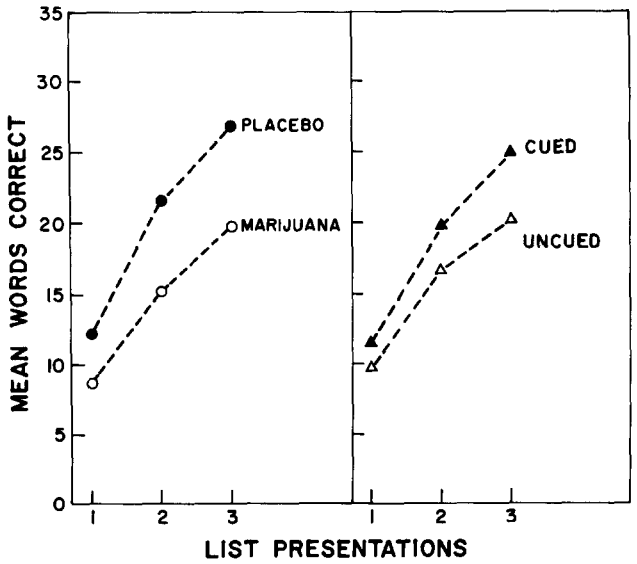

FIG. 1. Mean number of words recalled over three word list presentations as a function of drug and cueing conditions.

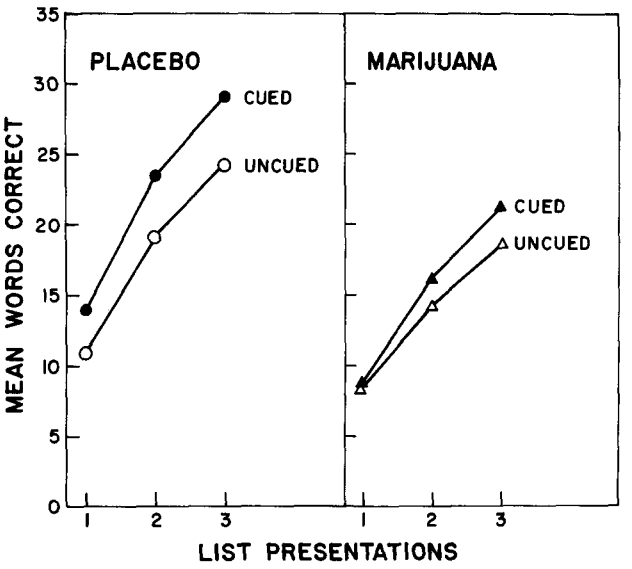

FIG. 2. Mean number of words recalled over three word list presentations under cued and uncued recall conditions for marijuana and placebo groups.

positive cueing effect was present in the P group on each of the three list presentations while the M group appeared to display a cueing advantage on the second and third list presentations only. This can be seen in Fig. 2. A cue x trial analysis of variance run separately for P and M groups confirmed these observations for the P group, a significant cueing effect was noted, $F(1,19) = 24.49$, $p<0.0002$. The main effect for lists was also significant, $F(2,38) = 232.18$, $p<0.0001$, but the cue x trial interaction was not. For the M group the cue effect did not reach significance, but the effect for trials did, $F(2,38) = 131.37$, $p<0.0001$. Of particular interest was the significant cue x list interaction, $F(2,38) = 5.00$, $p<0.01$, which indicated that cues were effective only on the last two lists. Multiple comparison tests indicated that the P group performed significantly better under the cued condition on each of the three lists ($p<0.05$; $p<0.001$; $p<0.001$). On the other hand the M group displayed superior performance on the second and third lists only ($p<0.01$; $p<0.01$).

Intrusions

The number of intralist and extralist intrusions for M and P groups was calculated. A 2 x 2 analysis of variance (cued versus uncued; M versus P) was performed on the number of extralist intrusions. Although no significant main effects were found, the cue x drug condition interaction did reach marginal significance, $F(1,38) = 3.74$, $p<0.06$. Multiple comparison tests revealed that the M group made significantly more intrusion errors in the cued condition in comparison to the P group, ($p<0.05$). No other comparisons were significant. A similar analysis for intralist intrusions revealed no significant main effect or interactions. There was no significant correlation between numbers of either type of intrusions and total recall in either group.

DISCUSSION

The present results indicate that recall of word lists was greatly reduced following intoxication with M in compari-

son to P. Retrieval cues were effective in making more information accessible than appeared to be available in both groups. However, cue presentation was not effective in increasing the recall of the M group to a level commensurate with the performance of the P group. In fact, the P group displayed a greater cued recall advantage when compared to the M group. Also, the absence of cues and intoxication produced an inferior rate of list acquisition in contrast to the presence of cues and P.

These findings differ somewhat with those reported by Eich *et al.* [12]. In that study, the use of retrieval cues eliminated asymmetrical dissociation produced by M. Thus, while cueing may attenuate drug state change deficits, the reduction in recall during the period of intoxication is not eliminated through the use of cues.

However, the type of retrieval cue employed is a variable which should be taken into account in evaluating the effectiveness of retrieval cues. The category cues employed by Eich *et al.* might be more powerful retrieval cues than initial letters of words. A more potent retrieval cue might allow partially learned items to be recalled. By partial learning it is meant that items of information are not stored in an all- or none fashion; rather, items are stored at different strengths or intensities. If recall of an item is dependent on it achieving some threshold level or strength, a more potent retrieval cue would better benefit recall. Thus, the signal strength of a to-be-remembered item following cueing would be increased allowing recall to occur [25]. While this hypothesis has intuitive appeal, there is no way to ascertain in advance whether a given cue is more potent than another. Cue potency is determined by whether a retrieval cue effectively increases cued recall over uncued recall. In the present study, first letter cues were quite powerful as retrieval cues in the P group, but not strong enough to eliminate the recall impairment in the M group. Other results from our laboratory also indicate that cues consisting of questions concerning a passage of prose do not eliminate the deficits produced in the free recall of this material (unpublished observations).

Previous studies concerning the effects of M on free recall have suggested that the mechanism by which the drug acts is to reduce the transfer of information from short term to long term storage. On the other hand, the recall of information learned prior to drug administration is not affected suggesting that retrieval processes are left intact [1, 8, 10]. In the present study, two hypotheses might be employed to account for the overall deficit in recall produced by M as well as the greater cueing advantage following placebo.

The discussion of the first hypothesis overlaps with the previous discussion concerning strength of items in storage. With the presentation of cues and multiple free recall trials, the trace of a word can be strengthened. The to-be-remembered word could be elicited as a implicit associative response to a cue, the cue acting to strengthen an originally subliminal trace. For example, in remembering the word chair, the implicit association made to the word might be table. Table strengthens the memory trace for chair. M might act to retard the formation of implicit associative responses and hence diminish trace strength. This would generally account for lower cued recall, less of a repetition effect, and slower acquisition during intoxication. But, this hypothesis appears to be more descriptive than explanatory and might be difficult to test. Furthermore implicit associative responses are more likely to be made when other words serve as cues rather than letters.

A second hypothesis which might contribute to an understanding of the present results has been described by Tulving and associates [22,24]. They have suggested that in free recall, storage per se is not the issue; rather, form of storage or accessibility is the important variable. If the material to-be-learned consists of items present in an individual's lexicon, the problem of storage is circumvented and remembering depends on the effectiveness of retrieval cues at the time of test. What is stored consists of ancillary information about the to-be-remembered items which segregates them from the rest of an individual's vocabulary. Cueing and multitrial free recall also have been shown to increase an individual's capacity for organizing material for recall [18,22]. This occurs mainly through the formation of interitem associations which usually results in clusters of items being emitted together. This process occurs for both cued and uncued recall except that in the latter, cues are self generated and are based on preexperimental associations [18]. Cued recall provides more structure, and indeed, on questioning, our P subjects indicated they were better able to cluster items with the use of cues. An examination of some individual records supported this contention, although the overall performance of a number of M Ss was too low to get any adequate measure of clustering. However, it is suggested that interference with this mechanism may be another way in which M attenuates recall.

Previous studies have [8,10] reported a significant increase in the number of extralist intrusions following intoxication employing free recall methods. The present study also noted this phenomenon, but the increase in intrusion errors occurred mainly in the cued rather than uncued condition. Interestingly, there was no significant correlation between number of external intrusions made and total number of words recalled. Darley and Tinklenberg [8] reported a similar finding. This suggests that deficits in recall following intoxication may not be directly related to intrusions occurring at the time of response. Although Dornbush [10] has suggested that the intoxicated subject lowers his criterion of acceptability, there by increasing false alarm rates, the present data suggest that recall is reduced during the period of intoxication over and above the number of intrusion errors made.

It can be argued that deficits in recall following intoxication can be a reflection of an altered motivational state. Indeed, some Ss suggested that they had difficulty "getting into the task". However, no S refused to perform the task and the results of other studies suggest that motiviational differences between intoxicated subjects and controls are not especially demonstrable [2]. Also, Darley and Tinklenberg [8] have suggested that if motivation to perform under M were reduced, then the deficit would show up on recall tests in which encoding took place under P and recall occurred in the intoxicated state. Studies cited in the introduction have shown that no detrimental performance is found under this condition.

In conclusion, the results of this study suggest that M produced a profound deficit in free recall which is only

partially reversed through the use of retrieval cues. The exact manner in which marijuana affected recall in this study cannot be elucidated. However, it was suggested that a diminution in strength of memory traces and/or interference with organizational ability could be induced by M leading to an impairment in free recall.

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