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Levels of Processing and Acute Effects of Marijuana on Memory[1]

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BELMORE, S. M. AND L. L. MILLER. *Levels of processing and acute effects of marijuana on memory.* PHARMAC. BIOCHEM. BEHAV. 13(2) 199–203, 1980.—Subjects' memory for lists of words was tested following the smoking of a single marijuana cigarette containing 1.4% Δ^9-THC or a placebo cigarette. During list presentation, each word was preceded by an orienting question which required one of four types of linguistic information (orthographic, phonetic, semantic, or syntactic). Free recall tests were administered immediately after each list (IFR) and following IFR for all five lists (FFR). Results indicated that subjects recalled fewer words while intoxicated with marijuana. There was no interaction between drug condition and level of processing in IFR, but a complex relationship mediated by time was seen in FFR. Drug subjects were more likely to forget meaningfully processed words on recently presented lists. The data provided little support for the hypothesis that marijuana differentially affects the processing and retention of different types of linguistic information.

Marijuana Free recall Linguistic information Levels of processing

A VARIETY of laboratory investigations have shown that marijuana intoxication produces reliable deficits in memory when tested by the method of free recall [1, 8, 9, 13, 14]. However, the mechanism through which memory is affected has not been elucidated. It has been suggested that marijuana intoxication may result in a reduced ability to integrate material in some meaningful fashion for recall to occur [16]. Analysis of conversational speech indicates that during intoxication latency of verbal response is increased; fewer syllables per phrase are spoken and prolongation of syllables is increased [18,20]. Furthermore, memory for prose is particularly susceptible to the disruptive effects of marijuana while simple rote memory (e.g. digit span) is only marginally affected [13]. These results suggest that marijuana may differentially impair the retention of meaningful material.

The levels of processing framework [6] provides a methodology for systematic investigation of the role of meaning in memory. This view was proposed as an alternative to multi-store models of memory which emphasize the transfer of information from short-term memory to long-term memory [2]. Craik and Lockhart [6] argued that the memory trace is a by-product of perceptual analyses, and that the durability of the trace is directly related to the "depth" or meaningfulness of initial processing. In the typical levels-of-processing paradigm, initial processing level is manipulated by means of orienting questions in an incidental memory task. The presentation of each word in a stimulus list is preceded by an orienting question which requires the analysis of either structural characteristics of the word (Does this word have four letters?) or the meaning of the word (Does this word represent a living thing?). A number of studies have supported the prediction that retention is better following meaningful than structural levels of initial processing [7,12].

Craik [5] has proposed that the levels of processing framework may also be useful in the investigation of pharmacological and biochemical factors in human memory. He suggested that impairments in memory following drug intoxication could result from changes in encoding or acquisition strategies based on the decreased ability to process information to a meaningful level. This suggests that the meaningfulness of to-be-remembered material could affect information processing during marijuana intoxication. That is, the intoxicated individual may experience difficulty in attaching meaningfulness to information to facilitate encoding.

The present study was designed to examine the effects of smoked marijuana on human memory with different types of cognitive processing. Following the procedure developed by Craik and his colleagues [6,7], initial processing was manipulated by means of different orienting questions accompanying the presentation of each word in a stimulus list. The questions involved four possible types of linguistic information: orthographic (the number of letters in the word), phonetic (rhyming relationships), semantic (category membership), or syntactic (compatibility with a sentence frame).

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Questions of the first two types focus attention on relatively superficial or structural aspects of the stimulus word, while the latter two require meaningful analysis of the word. The effect of marijuana on different levels of initial processing was assessed by comparing memory for words associated with orienting questions of each type.

METHOD

Subjects

Participants in this study were 16 male volunteers ranging in age from 21–28 years. All reported moderate private use of marijuana (2–3 times a week). Subjects were screened for mental and physical health by means of an interview, MMPI, a physical examination, and a series of laboratory tests including urinalysis, liver functioning, and electrocardiogram. Each subject was paid $20 for his participation in this experiment.

Design

Each subject in the study served as his own control under both sober and intoxicated conditions in two sessions separated by one week. In each condition, an equal number of to-be-remembered words were associated with each question type. The study was thus a completely within-subjects design with four factors: drug condition (placebo or marijuana), question type (letters, rhyme, semantic, syntactic), lists (1–5), and response type (yes or no). The dependent measure was the mean number of words recalled on an immediate free recall test (IFR) and final free recall test (FFR).

Materials

Stimulus words consisted of 160 monosyllabic concrete nouns ranging from 3–6 letters in length. All the words were A or AA frequency in Thorndike and Lorge's [19] printed word count. All were unambiguous as to syntactic category. The stimulus words were randomly assigned to 10 lists of 16 words each, with 5 lists designated as set A and the remaining 5 lists as Set B. Stimulus words were typed and mounted individually on $1\frac{1}{2} \times 1\frac{1}{2}$ inch slides.

A set of four orienting questions was generated for each stimulus word. The questions used the following frames, with words inserted as needed to fit each stimulus item: (1) Does this word have ___ letters? (Letter task); (2) Does this word rhyme with ___ ? (Rhyme task); (3) Does this word belong to the category ___ ? (Category task); or (4) Does this word fit in the following sentence: ___ ? (Sentence task). Comparison words used in the Rhyme task were always verbs or adjectives. The same answer (either yes or no) was correct for all four questions associated with a given stimulus word. For example, positive (yes) answers would be expected for the following questions for the stimulus word "HORSE": (1) Does this word have 5 letters?; (2) Does this word rhyme with COARSE?; (3) Does this word belong to the category ANIMALS?; (4) Does this word fit in the following sentence: THE ___ ATE THE APPLE? Correct answers to the orienting questions were assigned according to the experimenters' judgment and verified by pilot testing with an independent sample of subjects.

The orienting questions associated with a given stimulus word were randomly assigned to four different question lists. Each question list contained four questions of each type, two with yes answers and two with no answers; question types and response types were randomized within lists. Stimulus words were presented in the same random order for all subjects, but question lists were counterbalanced over subjects so that four subjects saw a given word with each question type.

Procedure

Each subject served in both a placebo and a marijuana condition in two group sessions separated by a one week interval. Half of the participants in each session were randomly assigned to a marijuana condition, and the other half to a placebo condition; a subject's assignment was reversed for the second session. Subjects were not informed as to their drug condition in either session. Set A stimulus words were presented to all participants in the first session and Set B in the second session.

Each subject smoked a single 1-gram marijuana cigarette containing 1.4% (14 mg) Δ^9-THC or a placebo cigarette from which all the THC had been extracted. Smoking materials were supplied by the National Institute on Drug Abuse. An *ad lib* smoking procedure was employed in which subjects were allowed to smoke in any manner they wished. However, they were instructed to inhale deeply, to hold the smoke in their lungs for 10–15 sec before exhaling, and to smoke as much of the cigarette as possible. During each session, level of intoxication was monitored by three pulse rate measures taken before smoking, after smoking (about 10 min later), and after presentation and immediate recall of all 5 stimulus lists (about 30 min after smoking). At the conclusion of each session, the subject was also asked to provide a numerical rating of both the potency of his smoking material and the subjective pleasantness of his experience, relative to past occasions of marijuana use, on a scale from 0 to 100.

Instructions describing the orienting questions and the free recall tasks were given before smoking and repeated before stimulus presentation began. Subjects were told to answer the orienting questions quickly but accurately, and instructed to use the questions as aids in remembering the words for later testing.

The stimulus words were projected onto a screen approximately 10 ft in front of the participants at the rate of 7 sec/word. As a word appeared, the subject moved a slotted cardboard shield to expose the next question on a printed question list, read the question silently, and indicated his response by circling either yes or no. After each list of 16 words, he turned to a blank recall sheet and was given 2 1/2 min for IFR. Approximately 10 min after completing the last stimulus list, subjects were given 5 min for FFR of all 5 lists.

RESULTS

Pulse Rate

The mean pulse rate prior to smoking was 79.5 beats/min for the placebo condition and 79.9 beats/min for the marijuana condition. Pulse rates immediately after smoking and 30 min after smoking (between IFR and FFR) were 80.8 and 75.7 beats/min, respectively, for the placebo condition and 97.2 and 86.6 beats/min for the marijuana condition. A two-way analysis of variance (ANOVA) for repeated measures (Drug Condition×Time) indicated that pulse rates changed over time, $F(2,30) = 17.19$, $p < 0.001$, and that marijuana significantly increased pulse rate in comparison to placebo, $F(1,15) = 16.10$, $p < 0.001$. The Dose×Time interac-

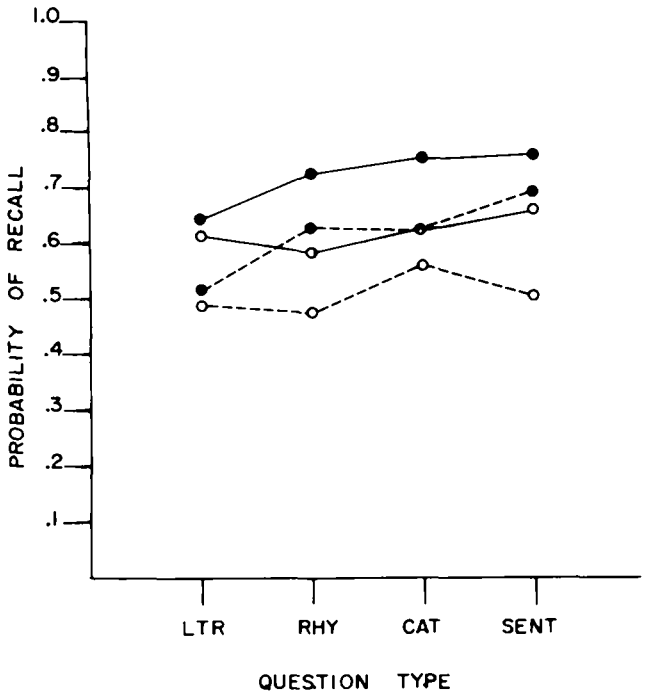

FIG. 1. Probability of initial free recall (IFR) for words associated with positive (●) and negative (○) questions for placebo (solid lines) and marijuana (broken lines) subjects.

tion, $F(2,30)=15.34$, $p<0.001$, indicated that a significant change in pulse rate occurred over successive measurements in the marijuana condition but not in the placebo condition. Increased pulse rate has been previously shown to be the most reliable physiological indicator of marijuana intoxication [4].

Pleasantness and Potency Ratings

In the marijuana condition, subjects rated their smoking materials as more potent and their experience as more pleasant (mean ratings 57.0 and 57.2) than in the placebo condition (11.6 and 22.5). One-way ANOVAS indicated highly significant differences between the marijuana and placebo conditions for both potency, $F(1,15)=59.07$, $p<0.001$, and pleasantness ratings, $F(1,15)=29.49$, $p<0.001$. Dose effects previously have been demonstrated for both pulse rate and subjective ratings of intoxication [14].

Orienting Task

Subjects made very few incorrect responses to the orienting questions; a mean of 1.88 (2.3%) errors occurred in the placebo condition and 2.8 (3.5%) in the marijuana condition. A three-way ANOVA (Drug Condition×Question Type ×List) showed no significant differences in performance over drug conditions or orienting questions.

Initial Free Recall (IFR)

The mean number of words recalled for each list, question type, and response type was calculated for the marijuana and placebo conditions. Drug effects for each question type (over lists) have been plotted in Fig. 1. The data were subjected to a four-way ANOVA for repeated measures (Drug Condition×Question Type×Response Type×List). Results of this analysis showed that all main effects were significant, with no significant interactions.

Marijuana intoxication was associated with a significant decrement in recall performance relative to the placebo condition, $F(1,15)=8.71$, $p<0.01$. This deficit is similar in magnitude to effects previously observed in our laboratory [14,16] and in others [8,9]. Although Fig. 1 suggests that marijuana may have had a slightly greater effect on the less meaningful (Letter and Rhyme) tasks, the expected Drug×Question Type interaction did not reach significance.

Overall recall was significantly affected by Question Type, $F(3,45)=4.85$, $p<0.01$. Planned comparisons using Tukey's Wholly Significant Difference (WSD) method showed that words for which subjects answered Category and Sentence questions were more accurately recalled than words following Letter or Rhyme questions ($p<0.05$). No other differences among question types were significant. These results are consistent with Craik and Lockhart's claim [6] that orienting tasks requiring meaningful processing produce greater retention. Questions eliciting yes answers also showed significantly better recall than questions requiring no answers, $F(1,15)=24.15$, $p<0.001$. The facilitatory effect of positive orienting questions on recall is a common finding in the levels of processing literature [7,17]. Moscovitch and Craik also reported that the superiority of positive questions is greater for meaningfully processed words; in the present study, however, the Question Type×Response Type interaction failed to reach significance.

A significant Lists factor, $F(4,60)=2.88$, $p<0.05$, reflected the fact that recall increased from list 1 to list 5, suggesting that a practice effect may have occurred. However, post-hoc comparisons indicated that only lists 1 and 4 differed significantly from one another suggesting a possible "warm-up" effect for list 1.

Final Free Recall (FFR)

Each word in the subject's FFR output was classified according to its original presentation list, question type, and response type. A four-way ANOVA for repeated measures was conducted on these scores.

As in IFR, intoxicated subjects showed an overall decrement in FFR, $F(1,15)=6.41$, $p<0.05$. However, the Drug effect in FFR was qualified by a complex three-way interaction with Lists and Question Type, $F(12,180)=1.93$, $p<0.05$. In order to clarify the basis for this interaction, separate three-way ANOVA's were performed for each of the five lists (Drug×Question Type×Response Type) and for each of the four question types (Drug×List×Response Type). Summarizing the results of these analyses, they indicated that: (a) only the most recently presented lists (lists 3–5) showed an effect for drug condition; (b) only the Sentence question condition showed a drug effect; and (c) all conditions but the Sentence question condition showed a list recency effect (better recall for recent lists). Thus, this interaction seems to reflect the fact that intoxicated subjects were differentially impaired in FFR of words associated with Sentence questions, especially in the most recently presented lists. Overall, retention was better for words with positive questions than negative, $F(1,15)=51.26$, $p<0.05$. A significant Question Type×Response Type interaction, $F(3,45)=3.05$, $p<0.05$, indicated that the superiority of posi-

tive questions occurred for every question type but Letters. Furthermore, the effect of question type was limited to positive responses, a finding consonant with Moscovitch and Craik's [17] results. For positive questions, Rhyme and Category (but not Sentence) tasks produced better recall than Letter questions. No significant task differences occurred for negative questions.

The FFR analysis also shows a significant effect of Lists, $F(4,60)=8.23$, $p<0.001$, with the most recently presented lists remembered best. Pairwise comparisons showed that lists 4 and 5 were remembered significantly better than lists 1 and 2. This list recency effect is consistent with data reported by Bugelski [3], but may also reflect the fact that the lists presented last were remembered better in IFR.

DISCUSSION

The goal of this experiment was to determine whether the memory deficit associated with acute marijuana intoxication was affected by the meaningfulness of the information to be remembered. Following a procedure developed within the levels-of-processing view of human memory [6], initial processing was manipulated by means of orienting questions which accompanied the presentation of each word. Free recall data were consistent with two main findings of the levels-of-processing literature. First, orienting questions which required meaningful processing produced better immediate recall than questions emphasizing structural characteristics of the words [7,12]. Second, recall was better for words associated with positive responses, especially for meaningful questions [7,17].

Intoxication with smoked marijuana produced a decrement in recall for both IFR and FFR. A number of previous studies have demonstrated the detrimental effects of cannabis derivatives on free recall [8, 14, 16]. The present data suggest that marijuana may produce a non-specific memory loss, since the magnitude of the deficit was only marginally affected by manipulations in level of initial processing. The only suggestion of such an interaction was seen in the FFR data, where intoxicated subjects were especially impaired in the recall of meaningfully processed words from recently presented lists. The interpretation of the latter result is not at all clear. With this qualification, these data provide little support for the hypothesis that marijuana differentially impairs the extraction or storage of different types of linguistic information.

It is of interest to note the congruence of these results with the findings of Hartley *et al.* [11] who recently investigated the effects of alcohol in a paradigm very similar to the procedure used here. Their data are entirely consistent with ours, since they show no evidence of an interaction between alcohol intoxication and level of initial processing. Both marijuana and alcohol thus seem to be similar in that they both have generalized effects on verbal functioning which may not be dependent upon the meaningfulness of processing.

Several alternative explanations for the lack of a Drug×Question Type interaction should be considered, however. One is that the effect of the orienting questions was mediated by idiosyncratic mnemonic strategies. In post-experimental interviews, some subjects reported using mnemonic plans involving meaningful verbal or imaginal associations. A faster rate of presentation may be necessary to eliminate this extraneous source of variability in initial processing. A second possibility is that the levels-of-processing paradigm used here is not sensitive enough to detect differential drug effects on different levels of linguistic analysis. Since a procedure which combines contextually isolated stimulus words and simple orienting questions may not engage the full range of the subjects' language processing abilities, sentences or connected prose material may be more appropriate stimuli for future investigations of this question. A third possibility is that the effects of meaningfulness in marijuana-induced memory deficits occur at the point of retrieval, not in initial encoding or acquisition. Empirical evidence for this possibility comes from reports that explicit retrieval cues can reduce or eliminate memory deficits associated with marijuana intoxication [10]. Moscovitch and Craik [17] have suggested that the orienting questions associated with stimulus words in a levels-of-processing task serve as implicit retrieval cues. They argue that the superior recall of items associated with positive questions is due to the greater specificity of positive questions as retrieval cues. This offers a possible interpretation of the data observed here.

The conditional FFR data (items recalled on both FFR and IFR) show a significant drug effect on positive but not negative question items. Following Moscovitch and Craik's analysis, this finding suggests that marijuana has a detrimental effect on the use of implicit retrieval cues, and that this effect is most pronounced on a delayed test of memory. In future research, it would be of interest to explore the role of meaningfulness in marijuana-induced memory deficits on recognition tests or on cued recall tests, where explicit retrieval cues are provided [15,16].

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