Memory & Cognition
1973, Vol. 1, No. 2. 196-200

Influence of marihuana on storage and retrieval processes in memory*

C. F. DARLEY, J. R. TINKLENBERG, W. T. ROTH
L. E. HOLLISTER, and R. C. ATKINSON†
Stanford University, Stanford, California 94305
and
Palo Alto Veterans Administration Hospital, Palo Alto, California 94304

Following presentation and immediate free recall testing of 10 20-word lists, 48 Ss were divided into two groups, one of which received an oral dose of marihuana extract calibrated to 20 mg of Δ^1-THC and one of which received placebo. One hour later, all Ss were administered delayed recall, recognition, and order tests on the first set of words. Presentation of another set of 10 lists followed, and there were immediate recall and delayed recall, recognition, and order tests on these words. Performance of drug and placebo Ss did not differ significantly for any of the first delayed tests. However, the performance of drug Ss was poorer than that of placebo Ss on immediate recall, delayed recall, and delayed recognition of the second set of lists. We concluded that retrieval of information relevant to the occurrence or nonoccurrence of an event was not affected by marihuana intoxication. Storage difficulties probably account for memory deficits due to the drug, and these difficulties appear to occur in the process of transferring information from short-term to long-term memory.

Previous studies (Tinklenberg et al, 1970; Melges et al, 1970; Abel, 1971a, b) have shown that marihuana intoxication causes decrements in the performance of certain memory tasks. Because many cognitive functions necessitate the reliable accessing of previously presented information, it is important to know precisely how marihuana influences memory processes. For information to be remembered, it must have been stored accurately in memory and it must be retrievable at the moment it is needed. The purpose of the present study was to determine whether the storage processes, the retrieval processes, or both are adversely affected by marihuana intoxication.

The experimental paradigm used was a variation of a standard free recall task. The variation introduced for the purpose of separating drug effects upon storage and retrieval processes was the administration of a delayed free recall test; this procedure has been used by Craik (1970) and involves having Ss recall as many words as possible from a prior series of free recall lists, each of which had been followed by an immediate free recall test. Delayed free recall is useful for drug research, since a drug may be administered during the interval between the immediate test on the final list and the presentation of the delayed test. The delayed recall performance of Ss receiving the active drug during that interval can be compared to the performance of Ss receiving placebo. The immediate recall scores provide a predrug measure of the equivalence of the two groups on word recall. In the present study, a delayed recognition test was also administered to determine if marihuana intoxication affects recognition and recall processes differently. In addition, for each item on the recognition test, Ss were asked to indicate in which list that item had appeared. Following the first set of delayed tests, drug and placebo groups were presented a new set of free recall lists, each followed by an immediate recall test; delayed tests were administered after immediate recall on the last list in the series. The presentation of a second series of lists was included to test for effects of marihuana upon free recall when list presentation occurs during drug intoxication.

*This research was supported by the van Ameringen Foundation and NIMH Grants 19918, 3030, and 21747.

†Requests for reprints should be sent to R. C. Atkinson, Department of Psychology, Stanford University, Stanford, California 94305. The authors thank Claire Darley, Vern Gates, Saul Kantor, Marilyn Lappin, Frances Moore, Pat Murphy, and Peggy Murphy for their technical assistance.

METHOD

The Ss were 48 adult males, all of whom were moderate (not more than once per week) social users of marihuana. They were paid $20 for 1 day of participation.

The Ss were tested in groups of eight, with two groups being tested each day. The E presented each group 10 lists of 20 words each, with the words being presented auditorily at a rate of 1 word every 3 sec. Each group of eight Ss heard the same words in the same order. Words for this first set of lists were unrelated nouns with frequencies of occurrence from 10 to 40 per million (Thorndike & Lorge, 1944). Immediately after presentation of each list, Ss were given a free recall test on the words from the preceding list (immediate recall). The Ss were instructed to write down in any order as many words as they could remember from the list they had just been presented; they were allowed 2 min to complete this test.

Upon completion of the immediate recall test on the 10th list, the group of eight Ss was divided randomly into two groups of four. These two subgroups went to separate rooms where, under double blind conditions, each S received an oral dose of either marihuana or placebo. Assignment of Ss to drug or placebo conditions was random, with the constraint that within each subgroup two Ss would receive marihuana and two placebo. Ss were told that varying doses of the drug, ranging from low to

Table 1
Sequence of Experimental Procedures

Elapsed time since drug administration	Experimental procedures
	Presentation and immediate recall of first 10 lists
	Drug Administration
1 h	Delayed tests on first set of lists
2 h	Presentation and immediate recall of second 10 lists
2½ h	Delayed tests on second set of lists

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

moderate strength, would be administered. Some Ss may have concluded that they had received a lower dose than others in their group, but all Ss had expectations of experiencing drug effects. Following drug administration, communication between Ss was forbidden in order to make it difficult for them to compare subjective effects.

After a 1-h rest period, Ss completed two types of delayed tests. The first was a delayed free recall test, in which they wrote in 20 min as many words as they could remember from all 10 lists. A 200-item three-alternative forced-choice recognition test was then administered (delayed recognition test). This consisted of 10 test sheets with each sheet containing 20 rows of three words per row. One word from each row had been presented on one of the lists, while the other two words were lures drawn from the same population as the previously presented words. The Ss were instructed to circle in each row the word they had seen earlier and to write next to the word an estimate of the list (1 to 10) in which it had been presented. The Ss were allowed 40 min to complete this test. They had not previously been told that they would be given these delayed tests.

Upon completion of the delayed tests on the first set of words, the original group of eight Ss was reformed; the group now contained four drug and four placebo Ss. The Ss were then presented 10 new lists of words, each list followed by an immediate recall test on that list. The procedure for presenting and testing this second set of lists was identical to that for the first set. Words for the second set were drawn from the Toronto Word Pool (Murdock & Walker, 1969), which consists of common two-syllable English words not exceeding eight letters in length with proper nouns, homophones, contractions, and archaic words omitted. There was no overlap between the words used in the second set of lists and those used in the first set, or as lures in the delayed recognition tests.

The Ss returned to their original subgroups and immediately received another series of delayed tests. On the delayed recall test, Ss were instructed to recall words only from the second set of lists, and the recognition test involved only words from that set. The latter test was again a three-alternative forced-choice test; the lures were drawn from the Toronto Word Pool and had not been used before in the experiment. As before, Ss were asked in which list each item had been presented. The times allowed for the delayed tests were the same as those for the delayed tests on the first set of words. As before, the Ss were not informed in advance that they would receive the second set of delayed tests.

Oral doses of the active drug were administered in the form of brownies containing NIMH marihuana extract calibrated to 20 mg of Δ^1-tetrahydrocannibinol (THC); the solvent was evaporated under nitrogen. Placebo Ss received brownies identical in taste and appearance containing marihuana from which all cannibinoids had been removed. Ss were required to fast for at least 8 h before the administration of the dose. The clinical syndrome produced by 20 mg of THC is approximately equivalent to that described by our Ss as typical for intoxication with marihuana in a social setting. Under fasting conditions, subjective and behavioral effects of an oral dose of this size have their onset about ¼ h after ingestion and are in evidence for at least another 3 h. So it was expected that the drug would be acting throughout the period of testing, with some Ss possibly nearing the end of the period of intoxication about the time the second delayed recognition test was completed. Peak effects for marihuana occur approximately 1-2 h following ingestion, coinciding with the administration of the first delayed tests. The schedule of list presentation and testing as it relates to the time of ingestion of the drug is summarized in Table 1.

RESULTS AND DISCUSSION

The results presented here are based upon data from 42 of the 48 Ss who participated in the experiment. Six Ss were deleted from the analysis for failing to complete the testing procedure in the prescribed manner; 3 of these Ss had received marihuana and 3 placebo. Although the marihuana and placebo Ss were treated identically prior to administering the drug, it is important to ensure that the two groups did not differ by chance on the initial recall task. Pooling data from all 10 lists of the first set, the probability that an item was recalled on the immediate recall test was identical for drug and placebo groups (.46). The left panel of Fig. 1 presents serial position curves for immediate recall of the first set of lists, with separate curves for drug and placebo groups. The curves for both groups show typical primacy and recency effects, and it is evident that not only is overall performance equal for the two groups, but probability of recall is virtually identical at each serial position.

Serial position curves for delayed recall and recognition performance are plotted for drug and placebo groups in the right panel of Fig. 1. As in immediate recall, the two groups did not differ on overall delayed recall [drug = .19, placebo = .18, $t(40) = .16$, $p > .80$]. The equality of the groups extends over all serial positions. Note that the recency effect so prominent in immediate recall disappears for delayed recall; this result is consistent with the findings of Craik (1970) and Darley and Murdock (1971).

The serial position curves for the delayed recognition test are virtually identical for the two groups. Overall probability of recognition for the drug (.68) and placebo (.71) Ss do not differ [$t(40) = .72$, $p > .40$]. The recency effect of immediate recall seems to persist in delayed recognition. Cohen (1970) has suggested that the successful recall of an item boosts the probability that it will be recognized on a delayed test; since terminal list items are recalled with a high probability on immediate tests, delayed recognition performance for these items should be relatively high by this reasoning.

The absence of differences between drug and placebo groups on delayed recall and recognition suggests that marihuana intoxication does not influence the retrieval of items stored in memory before drug intoxication. At least this is the case for the retrieval of information about whether or not a given item had been a member of

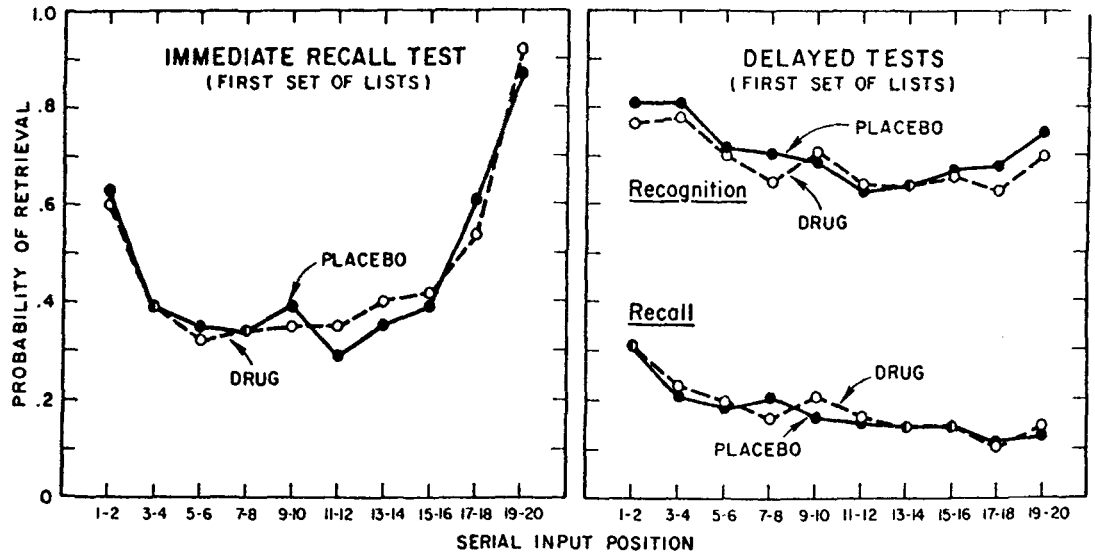

Fig. 1. The probability of immediate recall (left panel) and delayed recall and recognition (right panel) as functions of the seria input position of items from the first set of lists. Separate functions are plotted for drug and placebo groups.

a study list. There is other item information which may be stored as well, and in this experiment, Ss were tested on how well they could recall where an item had been presented within the series of 10 lists. It is possible that drug administration might prevent accurate retrieval of order information, even though the retrieval of information necessary for recall and recognition is uninfluenced. The measure used to compare drug and placebo Ss on the order task was the mean absolute deviation of the estimated list from the true list. Only estimates for correctly recognized words were used in the analysis. The mean deviation of 2.87 for the drug group was greater than the placebo group's deviation of 2.73, but the difference of .14 was not statistically significant [$t(40) = 1.27, p > .20$].

The performance of drug and placebo groups on the second set of tests can now be examined in the light of the finding that retrieval processes for recall and recognition of the first set of words are unaffected by marihuana intoxication. Serial position curves for the immediate recall tests on the second set of lists are presented in the left panel of Fig. 2. The shapes of the curves are strikingly similar for the two groups, but performance for drug Ss is depressed for nearly all serial positions. The difference in overall probability of recall between placebo (.46) and drug (.34) is highly significant [$t(40) = 3.37, p < .01$]. The serial position curves converge for the terminal list positions, a result

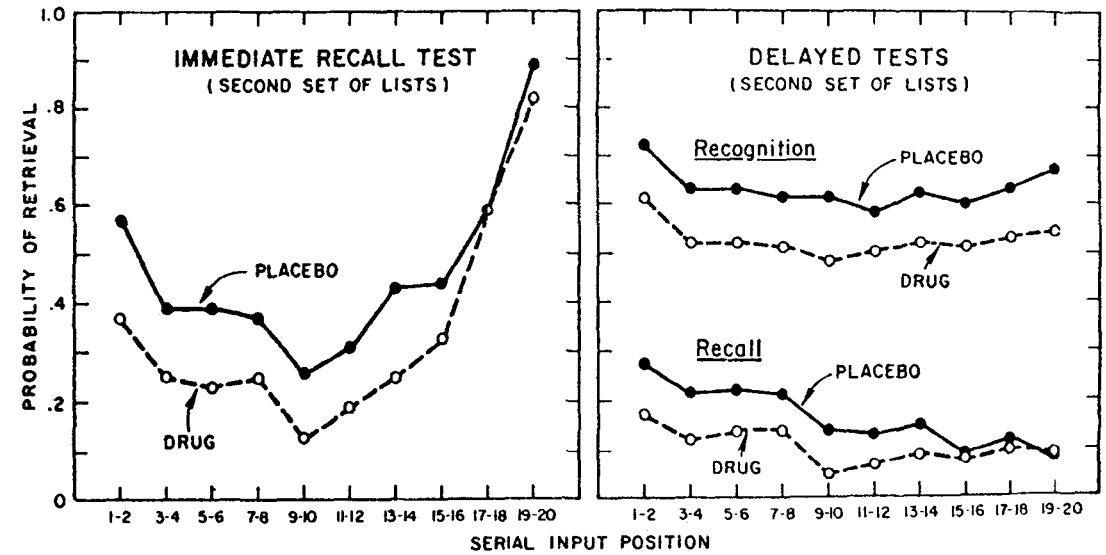

Fig. 2. The probability of immediate recall (left panel) and delayed recall and recognition (right panel) as functions of the seria input position of items from the second set of lists. Separate functions are plotted for drug and placebo groups.

which will be discussed later.

Serial position curves are plotted for the delayed recall and recognition tests in the right panel of Fig. 2. The results are as expected, given the differences shown for immediate recall. Drug and placebo Ss differ significantly in both delayed recall (placebo = .16, drug = .11, $t(40) = 2.05$, $p < .05$] and delayed recognition [placebo = .63, drug = .53, $t(40) = 2.34$, $p < .05$]. It is interesting to note that the groups differ even for terminal list positions in delayed recognition, even though the immediate and delayed recall curves converged for these items. On the second order-information test, the drug Ss again were less accurate in their estimates than were the placebo Ss. Mean absolute deviations were 3.10 for the drug group and 2.97 for the placebo group. However, the difference between groups was not significant [$t(40) = 1.08$, $p > .20$], and the fact that the mean values are based on different numbers of observations for the two groups (because of the different levels of delayed recognition performance) makes it difficult to interpret the result.

Abel (1971a, b) performed a series of experiments using a procedure similar to that used here, and he found that marihuana intoxication had no effect upon recall of previously stored information. However, performance on a delayed yes-no recognition test was adversely affected by the drug. The value of d′ for Abel's marihuana group was significantly lower than for either the placebo or no-drug control groups. This finding indicated that the marihuana Ss were impaired in their ability to discriminate between the words which had been presented previously and those which had not. The present results agree with Abel's regarding delayed recall, for we also found no differences between drug and placebo groups on the first delayed recall test. However, we found no drug vs placebo differences on the first delayed recognition test, a result incompatible with Abel's findings. In general, one would expect the d′ measure from the yes-no procedure to yield the same direction of effect as a percent correct measure in a forced-choice procedure, with the forced-choice procedure being somewhat more sensitive to experimental variables. The fact that we found no difference using the forced-choice procedure while Abel found a difference using a yes-no procedure is difficult to explain. Testing at different points of the drug's time course might produce such conflicting results, but the drug administration procedures were different in the two studies, and such a comparison is not possible. There are other differences in experimental methods, but none seem to offer an explanation of the discrepancy between the two sets of data. Our experiment is based on a large sample of Ss and was conducted using a highly controlled procedure. Thus, we feel that the findings are reliable; hopefully, future research will clarify the differences observed in the two studies.

In order to interpret the present results, it will be useful to make a distinction between storage and retrieval processes. We shall use the term storage to refer to the memory processes at work when to-be-remembered information is being studied by the S; retrieval will refer to those processes that permit the S to access memory and generate an appropriate response at the time of test. Using these definitions, the storage of information about the first set of lists is completed prior to the administration of the drug, and thus any difference between the drug and placebo groups on the first set of delayed tests must be due to changes in the retrieval process. Since the two groups were identical in their performance on the first set of delayed tests, we conclude that the retrieval stage of memory is not influenced by marihuana. On the other hand, both the study and subsequent tests on the second set of lists occurred after drug administration. Thus, differences in test performance between the two groups can be attributed to differences in storage, in retrieval, or in both processes. However, if we are willing to conclude from the first part of the experiment that marihuana does not influence retrieval, then the differences observed in the second part of the experiment must be interpreted as being due to differential storage in the drug and placebo groups. Stated otherwise, marihuana has a decremental effect on the storage phase of memory, but has no effect on the retrieval stage.

It could be argued that the pattern of results, instead of indicating differential storage and retrieval effects, simply reflects the changing potency of marihuana with the passage of time. In other words, the appearance of drug-placebo differences for the second set of tests might indicate that the peak drug effects coincide with the administration of these tests, whereas the absence of group differences for the first set of tests results from the relatively low drug potency prior to peak effects. From what is known about the time course of an oral dose of marihuana of the size used in this study, we consider this an unlikely possibility. As mentioned previously, peak effects undoubtedly occur for most Ss during the first delayed tests, with drug potency decreasing somewhat during the second set of tests. If time since administration were the crucial factor in determining performance, our results would not have been like those obtained.

The apparent convergence in Fig. 2 of the immediate recall curves over terminal positions may indicate how storage is affected by marihuana. The recency effect for immediate recall can be explained as resulting from the near-perfect retrieval of terminal list items from short-term memory (Atkinson & Shiffrin, 1968, 1971). If it is the case that terminal items are in short-term memory at the time of test, then the fact that performance of drug and placebo groups for these items is similar may mean that drug Ss enter information into short-term memory as well as do placebo Ss. In a previous study investigating marihuana effects upon reaction time in a short-term memory search task (Darley et al, in press), error rates were equal for drug

and placebo Ss. In that task, a correct response necessitates the accurate storage of a short list of items in short-term memory; the equal error rates are additional evidence that marihuana does not inhibit the entry of items into short-term memory. The storage difficulties of drug Ss in the present study may be at a later stage, involving the transferring of information from short-term memory to a longer-term memory.

The results presented here indicate that during marihuana intoxication, Ss are not deficient in their ability to retrieve information which had been stored in memory before ingestion of the drug. In contrast, marihuana does affect storage processes so that information processed during intoxication is not remembered as well. It appears that marihuana does not influence the likelihood of entering information into short-term memory, but rather its transfer to a longer-term memory.

REFERENCES

Abel, E. L. Retrieval of information after use of marihuana. Nature (London), 1971a, 231, 58.

Abel, E. L. Marihuana and memory: Acquisition or retrieval? Science, 1971b, 173, 1038-1040.

Atkinson, R. C., & Shiffrin, R. M. Human memory: A proposed system and its control processes. In K. W. Spence and J. T. Spence (Eds.), *The psychology of learning and motivation: Advances in research and theory.* Vol. 2. New York: Academic Press, 1968.

Atkinson, R. C., & Shiffrin, R. M. The control of short-term memory. Scientific American, 1971, 225, 82-90.

Cohen, R. L. Recency effects in long-term recall and recognition. Journal of Verbal Learning & Verbal Behavior, 1970, 9, 672-678.

Craik, F. I. M. The fate of primary memory items in free recall. Journal of Verbal Learning & Verbal Behavior, 1970, 9, 143-148.

Darley, C. F., & Murdock, B. B. Effects of prior free-recall testing on final recall and recognition. Journal of Verbal Learning & Verbal Behavior, 1971, 91, 66-73.

Darley, C. F., Tinklenberg, J. R., Hollister, L. E., & Atkinson, R. C. Marihuana and retrieval from short-term memory. Psychopharmacologia, in press.

Melges, F. T., Tinklenberg, J. R., Hollister, L. E., & Gillespie, H. K. Marihuana and temporal disintegration. Science, 1970, 168, 1118-1120.

Murdock, B. B., & Walker, J. Modality effects in free recall. Journal of Verbal Learning & Verbal Behavior, 1969, 8, 665-676.

Thorndike, E. L., & Lorge, I. *The teacher's word book of 30,000 words.* New York: Bureau of Publications, Teachers College, Columbia University, 1944.

Tinklenberg, J. R., Melges, F. T., Hollister, L. E., & Gillespie, H. K. Marihuana and immediate memory. Nature, 1970, 226, 1171-1172.

(Received for publication December 27, 1972;
revision received January 16, 1973.)