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Marijuana and Memory Impairment: Effect on Free Recall and Recognition Memory[1,2]

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MILLER, L. L., D. MCFARLAND, T. L. CORNETT AND D. BRIGHTWELL. *Marijuana and memory impairment: effect on free recall and recognition memory.* PHARMAC. BIOCHEM. BEHAV. 7(2) 99–103, 1977. – The effect of marijuana on memory was evaluated by presenting two groups of 17 male volunteers with lists of repeated or nonrepeated words following administration of a single marijuana cigarette containing 14 mg Δ^9-THC. An immediate free recall, final free recall and recognition memory test followed. Results indicated that marijuana significantly decreased immediate and final free recall but only slightly influenced recognition memory. Rate of acquisition on the repeated lists was the same for both groups. Long term retention of encoded information was not influenced by marijuana. The shape of the serial position curves departed slightly from those reported by other investigators in that some effects of the drug on the recency portion of the curve were noted. Both internal and external intrusions were elevated under marijuana.

Marijuana Free recall Recognition memory Retention Serial position curve Intrusions

DESCRIPTIONS of the acute intoxication syndrome following marijuana smoking are filled with accounts of lapses in recall ability [19]. Objective substantiation of memory deficits during marijuana intoxication has been reported by a variety of investigators employing free recall paradigms [1, 5, 7, 16]. Based on the dual process memory model proposed by Shiffrin and Atkinson [21], a number of these latter investigators have suggested that the major effect of marijuana on the memory process is to retard the passage of information from a short term to a long term storage component. This hypothesis is based mainly on the finding that the initial portion of the serial position curve for free recall (primacy effect) is reduced by marijuana in comparison to placebo while the later portion (recency effect) remains unaltered. A serial position curve is a U-shaped function relating probability of recall to serial position of input items. Since the beginning and end of the serial position curve respond differentially to a range of experimental manipulations, the positions are thought to represent output from different storage mechanisms.

One purpose of the present study is to assess the effect of marijuana on repeated free recall of same and different word lists. Repeated presentation and recall of the same material provides for the assessment of the effects of marijuana on memory consolidation while repeated presentation and recall of different lists would indicate the degree to which practice in recalling would influence the effect of the drug.

A second purpose was to evaluate the effect of marijuana on intrusion errors. In recall experiments involving marijuana smoking, these usually consist of the introduction of intralist or extralist intrusions [5,16], the introduction of unrelated, extraneous material during the recall of prose [8,18] or a high incidence of false alarms in recognition memory tasks [1]. It is important to know whether these types of errors constitute the major source of recall deficit following intoxication.

The final purpose of the present experiment was to ascertain how well information would be retained following marijuana providing initial recall had occurred. This was determined by calculating the proportion of items immediately recalled that were available on a final free recall test.

METHOD

Subjects

Thirty-four male volunteers between the ages of 21–28 participated in the study. All were considered moderate users of marijuana (2–4 times per week). Prior to the study, each subject was screened for mental and physical health employing a brief interview, MMPI, a physical examination and a series of laboratory tests including a liver function test, urinalysis and electrocardiogram. All subjects were paid for their participation.

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Drug Administration

Marijuana cigarettes supplied by NIDA were employed as smoking materials. Subjects smoked a single one gram marijuana (M) cigarette containing 1.4% Δ^9-THC (14 mg) or a placebo (P) cigarette from which all THC had been exhausted. A group of four to five subjects smoked together with some receiving P and some M. Subjects were allowed to smoke in any manner they desired, but were instructed to finish as much of the butt as possible. Smoking took approximately 10 min and all testing was completed in a quiet, comfortable room.

Pulse rate measures were taken before smoking, immediately after smoking, 15 min, 50 min and 115 min following smoking with the last measure following the completion of testing. At the end of testing each subject rated the intensity of this high (potency) and its pleasantness on a 0–100 point scale.

Design and Procedure

Upon arrival in the laboratory, subjects were randomly assigned to a M or P group. They were given a 10 min rest period and then provided with instructions regarding the task they were to perform. Smoking was subsequently initiated. Following smoking, twenty word lists containing 15 words each were presented aurally at the rate of one word every three seconds. All words were of the A or AA variety taken from the Thorndike-Lorge norms [23]. After each list, two min were given to write down as many words as could be remembered. This was the immediate free recall test (IFR). After presentation of list 10 and 20 a final free recall (FFR) was instituted which involved copying down all the words which could be remembered from the prior ten lists. At the end of the study a delayed recognition memory test was given. Subjects were presented with a list of 510 words, 255 of which were seen before and 255 which were used as lures. Subjects were told to circle the words they had seen before. In an effort to determine the effect of marijuana on same list acquisition a single list was repeated four times at positions 1,6,11 and 16. Subjects were not told that the list would be repeated. This method was introduced originally by Hebb [11]. All experimental procedures are outlined in Table 1.

TABLE 1

SCHEME OF EXPERIMENTAL PROCEDURES

Elapsed time since completion of smoking (min)	
	Ten Minute Rest Period
	Instructions
	Pulse Rate Measure
	Drug or Placebo Administration
1	Pulse Rate Measure
15	Pulse Rate Measure
20	IFR Lists (Lists 1–10)
40	FFR Test
50	Pulse Rate Measure
70	IFR Lists (Lists 11–20)
90	FFR Test
100	Recognition Memory Test
115	Pulse Rate

RESULTS

Pulse Rate

M produced a significant overall elevation in pulse rate in comparison to P, $F(1,32) = 13.12$, $p<0.001$. Pulse rate changed over successive measurements, $F(4,128) = 60.80$, $p<0.0001$, and drug condition interacted significantly with time of measurement, $F(4,128) = 26.58$, $p<0.0001$. Newman-Keuls multiple comparison tests indicated that pulse rate in the M group was significantly elevated immediately and fifteen minutes after smoking, $p<0.01$ (a rise to approximately 102 BPM) but began to return to near control levels at 50 min and was back to control levels at 115 minutes. Pulse rate measures in the P condition remained invariant across successive measurements. These results are consistent with those of other investigators [6,14].

Potency and Pleasantness Ratings

M smokers rated their smoking material as significantly more potent than did subjects in the P condition, $F(1,32) = 25.76$, $p<0.001$. Pleasantness ratings likewise were elevated under M, $F(1,32) = 9.14$, $p<0.005$. The mean potency and pleasantness ratings for the M condition were 56.47 and 58.23 and for the P condition 18.35 and 31.59, respectively. Potency and pleasantness ratings were highly correlated with each other, $r = .76$, $p<0.0001$. Potency ratings were significantly correlated with pulse rate immediately, 15 and 20 min after smoking ($r = .44$; .56 and .55, all $p<0.009$).

Recall Over Same and Different Lists

The mean number of words recalled per list over the 16 nonrepeated lists was 7.94 for the P condition and 5.99 words for the M condition. This difference was highly significant, $F(1,32) = 10.06$, $p<0.004$. However, the number of words recalled per list remained invariant over lists under both P and M suggesting that practice effects exerted little or no influence on recall. The mean number of words recalled over successive blocks of four lists is presented in Fig. 1 for both P and M conditions.

The mean number of words recalled with repeated presentation of the same list increased significantly over trials, $F(3,96) = 25.52$, $p<0.0001$, with subjects in the P condition displaying superior recall across lists, $F(1,32) = 10.25$, $p<0.004$. There was no significant interaction between drug condition and list presentation indicating that rate of list acquisition was not differentially affected by M.

Serial Position Curves – Immediate and Delayed Recall

The serial position curves which reflect number of words recalled as a function of input serial position are presented in Fig. 2. A U-shaped serial position curve was found for both treatment conditions following immediate recall, $F(4,128) = 84.39$, $p<0.0001$, with M producing inferior recall in comparison to P at all serial positions, $F(1,32) = 10.08$, $p<0.004$. Drug condition did not interact with the shape of the serial position curve.

In the right side of Fig. 2 serial position curves for the FFR test are presented. Recall on the FFR test is also

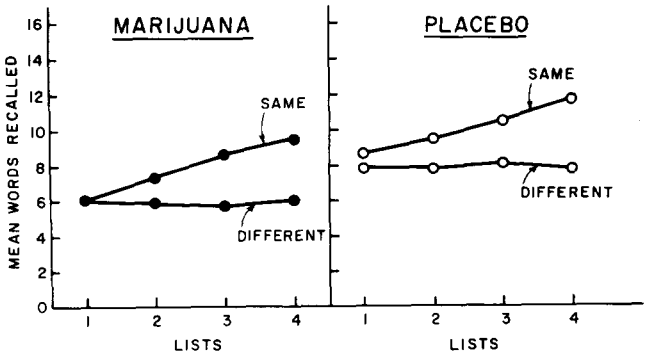

FIG. 1. Mean number of words recalled over repeated (same) and nonrepeated (different) lists. Recall for the 16 nonrepeated lists is presented in blocks of four lists.

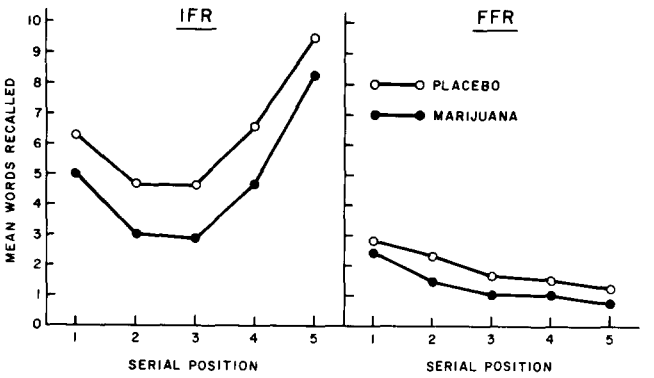

FIG. 2. Mean number of words recalled for immediate free recall (IFR) and final free recall (FFR) as a function of serial input position of items on nonrepeated lists.

plotted as a function of the initial serial input position of a word. As in the IFR test, serial position curves developed for both P and M groups, $F(4,128) = 84.39$, $p<0.0001$. However, no differences existed between the two groups with regard to shape of the curves. It should be noted that terminal items in the list were recalled more poorly than middle items on the FFR test. This phenomenon has been termed the negative recency effect and has been frequently reported [24]. The difference between M and P in total number of words recalled on the FFR tests was marginally significant, $F(1,32) = 3.83$, $p<0.06$. The P group also maintained its superiority on the FFR tests following repeated presentations of the same list $F(1,32) = 4.45$, $p<0.04$.

On the initial free recall test, 39.70% of the items presented were recalled under P while 30.00% were recalled following M. These values dropped to 12.8% and 9.3%, respectively, for the P and M conditions on the FFR recall test.

Intrusions

Two types of intrusion errors were calculated, internal intrusions which consisted of the introduction of words during recall which were contained in lists presented prior to a given immediate recall test and external intrusions which consisted of words not contained on any of the word lists.

There was no overall difference in number of intrusion errors made under M and P, but significantly more external than internal intrusions were committed, $F(1,32) = 34.67$, $p<0.0001$. Drug condition interacted significantly with type of intrusion error, $F(1,32) = 5.66$, $p<0.02$. While the number of internal intrusions made under P and M did not differ, Newman-Keuls multiple comparison tests indicated that significantly more external intrusions were made following M, $p<0.05$.

Two other types of intrusion errors were calculated for FFR. These consisted of external intrusions and another type of internal intrusion error consisting of items from the first block of ten lists that were recalled on the second FFR test. The numbers of both of these intrusion errors were elevated significantly in the M condition, $F(1,32) = 5.73$, $p<0.02$. Unlike the IFR results, the interaction between drug condition and intrusion type was not significant.

Correlations were computed between the various intrusion measures and free recall and recognition. External intrusions during initial recall, final recall, and internal intrusions during initial recall were all positively correlated ($r = .51$ to 72, $p<0.002$ in all cases). The only other significant correlation involving intrusions was between initial recall and internal intrusions ($r = .36$, $p<0.04$). Initial recall and final recall were highly correlated ($r = .88$, $p<0.0001$), and hit rates during recognition memory were significantly correlated with both of these free recall scores ($r = .35-.56$, $p<0.05$ in all cases). Finally, hits and false alarms during recognition testing were significantly correlated ($r = .52$, $p<0.0005$).

Retention of Recalled Items

An attempt was made to determine whether items recalled on the IFR test would also be recalled on the FFR test. An estimate of the number of items retained following their immediate recall was expressed in terms of a conditional probability score which was calculated for each subject. This score consisted of the proportion of items recalled on the FFR test given correct recall on the IFR test (R2/R1). A second probability score consisting of the proportion of items recalled on the retention test given that recall did not occur on the IFR test (R2/N1), was also calculated. Items on the repeated lists were not included in this analysis.

An analysis of variance was performed with drug condition and probability type as main effects. No significant differences were found between M and P groups in the magnitude of these two probability scores. As expected, R2/R1 was significantly higher than R2/N1, $F(1,32) = 256.88$, $p<0.0001$, indicating that if an item was recalled on the IFR it was more likely to be recalled on the FFR than if it was not recalled on the IFR. However, the R2/R1 probability was quite low, 0.26 for the P group and 0.23 for the M group. If a high proportion of items recalled on the IFR were being retained, the R2/R1 probability score would be closer to 1. The R2/N1 probability scores were approximately 0.03 for both groups which indicated that if an item was not recalled initially it was very unlikely to occur on the FFR test.

RECOGNITION MEMORY

Recognition memory was analyzed by calculating the hit rates (correctly identifying an item as old) and false alarm rates (incorrectly identifying a lure as old). The total

number of both of these types of recognition errors did not differ for P and M; but the interaction of drug condition and error type did reach significance, $F(1,32) = 3.57$, $p<0.06$. Under both conditions, hit rates were 39.6% and 36.6%, respectively. However, Newman-Kuels tests indicated that the false alarm rate was significantly elevated in the M condition in comparison to P (21.15% vs 11.70%), $p<0.05$.

Since a recognition memory task involves responding to each item with a yes or no response, hit rates can be artificially inflated if a subject simply responds yes to most items. On the other hand, a subject can be very conservative in his responding and respond no to most items thereby keeping his false alarm rate at zero. Usually a subject employs a bias in responding which falls somewhere between these two extremes. Thus, memory strength on a recognition memory test can be assessed only by taking response bias into account. Therefore, measures of sensitivity, d', and response bias, β, derived from signal detection theory [9] were employed. The measure d' is an unbiased indicator of memory strength and consists of the difference in means between target and lure distributions. The measure β, is a measure of a subject's criterion location which lies on an abscissa which demarcates the overlap between target and lure distributions. The area to the one side of this value is the probability that an observation from the lure distribution will exceed the criterion value leading to a yes response. The area to the other side of the criterion is the probability that an observation from the target distribution will exceed the criterion value resulting in a yes response.

A parametric measure of sensitivity, d'e, [3] was calculated along with a nonparametric measure Ag [10]. Neither measure was found to correlate with the other indicating that the target and lure distributions did not fulfill the criteria of normality. Therefore, the nonparametric measure was subjected to further analysis. No significant effects for drug condition were obtained for either the measure of sensitivity, Ag, or a nonparametric measure of bias, β' [10] as determined by the Mann-Whitney U statistic.

DISCUSSION

The present results indicate that M in comparison to P reduced both IFR and FFR of verbal material, which confirmed the results of previous studies. The effect of the drug on IFR was not attenuated by either practice on different lists or by repetition of the same list. Recognition memory was only mildly affected by M.

Performance remained inferior following intoxication on all lists and invariant across nonrepeated lists for both groups indicating that within session practice effects did not occur. Previous studies employing alcohol have indicated that practice on a task attenuated the effect that alcohol subsequently had on performance [22]. Two M studies have obtained divergent results with regard to practice on psychomotor tests prior to M intoxication [2,20]. It should be noted that the former studies examined intrasession practice effects while the present study assessed intersession practice effects. However, the subjects employed in the present study all had extensive practice on memory tasks especially free recall. Whether practice between sessions would attenuate M free recall deficits is still open to question.

The serial position curves for both IFR and FFR correspond reasonably well with those reported by others [1,5], except that in our study some reduction in recall in the terminal portions of the word lists was noted. Darley and Tinklenberg [5] found that the recency portion of their serial position curve was unaffected by M while recall from the initial and middle portions of the curve was lowered. They interpreted these results to mean that M reduced the passage of information from a short term to long term storage component. Retrieval appeared not to be affected since marijuana administered following list acquisition did not alter list recall or shape of the serial position curve. Although the serial position results in the present study correspond fairly well to those reported by Darley and Tinklenberg [5] other aspects of our data do not support their conclusions.

First, the recognition results do not support their data but come closer to those reported by Dornbush [7]. While false alarm rates were elevated following intoxication and hit rates mildly depressed, both d' and β values were essentially equivalent in both groups. These findings suggest that memory strength as measured by a recognition test is similar in both groups. Two factor memory theory proposes that recognition memory is a measure of storage while recall is a measure of both storage and retrieval [15]. According to Kintsch [13] recognition involves "checking the familiarity or response strength of an item, but recall involves an additional process of search or retrieval". Whereas, deficits in recall and recognition could be interpreted as being due to a storage problem, deficits in recall but not recognition could be interpreted as a retrieval failure. However, it should be noted that hit rates on the recognition test were quite low, between 35 and 40%, making any final conclusions concerning the storage-retrieval dichotomy tenous.

Another finding in the present study provides some difficulty for the reduced transfer explanation of the effect of M on memory. Although recall was lowered on repeated lists, the rate of acquisition (amount of information incorporated into memory on each trial) did not differ for P and M groups. A similar gain of information occurred on each trial. A divergence of the two learning curves might be expected if less information was incorporated on each trial following M. However, parameters influencing acquisition following M intoxication need further investigation since a previous study reported some evidence for inferior acquisition rate on repeated lists in the intoxicated state [16].

Long term retention was reduced following intoxication but was equal when a correction for initial recall levels was made. This was reflected in the conditional probability analysis which along with the repeated list results suggests that M does not increase the rate of forgetting following recall.

A number of different types of intrusion errors were elevated following intoxication which is consistent with previous results. Although the different types of intrusion errors were intercorrelated, the correlation between the intrusions and various measures of recall were quite low. It seems that intrusions reflect some nonspecific noise in the system but do not systematically relate to the memory process. They constitute a factor which appears independent of recall. Whether they can be considered a source of interference which can influence recall is not indicated in the data.

The findings that M reduces recall of nonrepeated lists,

has little effect on the amount of information gained during repeated presentation of the same list and produces only mild changes in recognition memory are somewhat difficult to interpret. M appears to interfere with initial encoding of information into storage as measured by a single free recall trial by possibly attenuating trace strength of an item or by interfering with the formation of associations between items in the list. However, with repetition elaborative and coding operations which have to be performed to set up a word for later retrieval are reduced or at least modified. The fact that rate of improvement in recall is similar for both groups further suggests that items from intervening lists do not displace repeated items in memory. Thus, one effect of the drug is to interfere with the initial formation of a memory trace.

Recognition memory was only mildly affected by M in the present study. One factor which may determine the appearance of recognition deficits in following M intoxication is whether the recognition test is presented subsequent to a free recall test. It has been previously shown that M produced little effect on a recognition test not preceeded by a free recall test [17]. Another factor which must be considered is the type of lures employed in the recognition test. If the lures are similar in some way to the target items, the distribution of hit and false alarm rates might be different than when the lures employed are unlike the target items.

Models of memory which might encompass these results have been proposed by Kintsch [13] and Wickelgren [25]. The basic assumption of these models is that items of information entering into memory are not stored in an all or none fashion, but are stored at different strengths or intensities. This concept of memory trace strength is similar to the Hullian notion of habit strength [12]. Kintsch [13] speaks of familiarity rather than strength. If an item is below some threshold strength for recall, repeating the item, or presenting the item in the context of a recognition test could increase its signal strength so that it can be remembered. When false alarm rates are elevated in a recognition test following intoxication, it may mean that lures overlap semantically or associatively with the to-be recognized items to the extent that their familiarity or strength increases in memory. This effect might be very pronounced if a recall test occurs prior to the recognition test because recall may be partially dependent on the formation of interitem associations which are based on preexperimental experiences. Thus, M could produce a change in the false alarm rates by increasing the strength of preexperimental associations or by strengthening the existing associations between lures and target items.

In conclusion, describing the actions of marijuana on the memory process in terms of any single theory of memory may prove difficult at the present time. An empirical analysis seems most appropriate with theories of memory serving as working models rather than explanatory devices.

REFERENCES

1. Abel, E. L. Marihuana and memory: Acquisition or retrieval? *Science* **173:** 1038–1040, 1971.
2. Beautrais, A. L. and D. Marks. A test of state dependency effects in marihuana intoxication for the learning of psychomotor tasks. *Psychopharmacologia* **46:** 37–40, 1976.
3. Clarke, F. R., T. G. Birdsall and W. P. Tanner, Jr. Two types of ROC curves and definitions of parameters. *J. Am. Acous. Soc. Amer.* **31:** 629–630, 1959.
4. Craik, F. I. M. The fate of primary memory items in free recall. *J. Verb. Learn. Verb. Behav.* **9:** 143–148, 1970.
5. Darley, C. F. and J. R. Tinklenberg. Marihuana and memory. In: *Marijuana: Effects on Human Behavior,* edited by L. L. Miller. New York: Academic Press, 1974.
6. Domino, E. F. Neuropsychopharmacologic studies of marijuana. Some synthetic and natural THC derivatives in man. *Ann. N.Y. Acad. Sci.* **197:** 166–191, 1971.
7. Dornbush, R. L. Marijuana and memory: Effects of smoking on storage. *Ann. N.Y. Acad. Sci.* **234:** 94–100, 1974.
8. Drew, W. G., G. F. Kiplinger, L. L. Miller and M. Marx. Effects of propranolol on marihuana-induced cognitive dysfunctioning. *Clin. Pharmac. Ther.* **13:** 526–533, 1972.
9. Green, D. M. and J. A. Swets. *Signal Detection Theory and Psychophysics.* New York: Wiley, 1966.
10. Grier, J. B. Nonparametric indexes for sensitivity and bias: Computing formulas. *Psychol. Bull.* **75:** 424–429, 1971.
11. Hebb, D. O. Distinctive features of learning in the higher animal. In: *Brain Mechanisms and Learning,* edited by J. B. Delafresnaye. New York: Oxford University Press, 1961.
12. Hull, C. L. *Principles of Behavior.* New York: Appleton-Century-Crofts, 1943.
13. Kintsch, W. Models for free recall and recognition. In: *Models of Human Memory,* edited by D. A. Norman. New York: Academic Press, 1970.
14. Manno, J. E., B. R. Manno, G. F. Kiplinger and R. B. Forney. Motor and mental performance with marijuana: Relationship to administered dose of Δ^9-tetrahydrocannabinol and its interaction with alcohol. In: *Marijuana: Effects on Human Behavior,* edited by L. L. Miller. New York: Academic Press, 1974.
15. McCormack, P. D. Recognition memory: How complex a retrieval system. *Can. J. Psychol.* **26:** 19–41, 1972.
16. 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:** 639–643, 1976.
17. Miller, L., T. Cornett, W. Drew, D. McFarland, D. Brightwell and A. Wikler. Marijuana: Dose-response effects on pulse rate, subjective estimates of potency, pleasantness and recognition memory. *Pharmacology* **15:** 268–275, 1977.
18. Miller, L. L., W. G. Drew and F. G. Kiplinger. Effects of marijuana on recall of narrative material and stroop colour-word performance. *Nature* Lond. **237:** 172–173, 1972.
19. Paton, W. D. M. and R. G. Pertwee. The actions of cannabis in man. In: *Marijuana: Chemistry, Pharmacology, Metabolism and Clinical Effects,* edited by R. Mechoulam. New York: Academic Press, 1973.
20. Peeke, S. C., R. T. Jones and G. C. Stone. Effects of practice on marijuana-induced changes in reaction time. *Psychopharmacology* **48:** 159–163, 1976.
21. Shiffrin, R. M. and R. C. Atkinson. Storage and retrieval processes in long term memory. *Psychol. Rev.* **76:** 179–193, 1969.
22. Tarter, R. E., B. E. Jones, C. D. Simpson and A. Vega. Effects of task complexity and practice on performance during acute alcohol intoxication. *Percept. Mot. Skills* **35:** 875–882, 1971.
23. Thorndike, E. L. and I. Lorge. *The Teachers Word Book of 30,000 Words.* New York: Columbia University Press, 1944.
24. Watkins, M. J. and O. C. Watkins. Processing of recency items for free recall. *J. exp. Psychol.* **102:** 488–493, 1974.
25. Wickelgren, W. A. Multitrace strength theory. In: *Models of Human Memory,* edited by D. A. Norman. New York: Academic Press, 1970.