trials) was achieved after a mean of eight trials with no significant differences between the three groups, which probably indicates no deficit in inhibiting a previously learned response.

The behavioral effects of acutely elevated concentrations of alcohol in the blood are well documented (*11*). However, there are no reports of the effects of chronic ingestion of ethanol and appropriate control diets upon animal learning after the cessation of the acute effect of ethanol. Whereas it appears well established that thiamine deficiency may cause a memory defect and neurological symptoms in man, whether associated with chronic alcoholism or not (*1*), the possibility must be considered that chronic ethanol consumption itself may also be deleterious to the brain. The demonstration of such a direct effect of ethanol or its metabolites upon brain function may imply that not all toxic effects of chronic ethanol consumption upon the brain can be prevented by the administration of vitamins.

The diets selected for this investigation were nutritionally adequate as documented by composition (*2*, *4*), body weight comparison, and absence of clinical signs recognized as associated with vitamin deficiencies of mice (*12*). There was no significant weight loss due to consumption of the ethanol-containing diet in the mouse strain (C-57) used in this study, which has a high preference for alcohol. The previously described temporary weight loss (*2*, *4*) in a mouse strain with a low preference for ethanol (ICR-DUB) consuming a comparable diet was not observed under the conditions of this experiment. The possibility that ethanol in the diet resulted in decreased absorption of vitamins under the conditions of this experiment is highly unlikely in view of the nearly identical serum folate and vitamin B_{12} concentrations in both ethanol- and sucrose-consuming groups. There was no evidence of anemia in any of the groups. The calculated intake of all vitamins consumed under the conditions of this experiment (*2*, *4*) ranged from 1½ to 2 times that required for growing mice (*13*), whereas decreased absorption of vitamins reported in some chronic alcoholic patients is on the order of magnitude from 0 to 40 percent of the administered dose (*14*).

The possibility exists that the differences in performance between the ethanol- and sucrose-consuming groups is secondary to a stress reaction and chronically increased release of adrenal corticotropic hormone (ACTH) and adrenal corticoid caused by the effects of ethanol. It is highly unlikely that under the conditions of this experiment ethanol represented a significant stressor in view of normal adrenal weights and histology. Chronic release of ACTH and stress are known in rodents to increase the adrenal weight two- to threefold by the end of the second week (*15*). Furthermore, almost all available evidence suggests an improved performance of avoidance conditioning under various conditions of stress or increased concentrations of adrenal steroid (*16*). If ethanol had induced stress under the conditions of this experiment, then this should have served to diminish the observed differences in performance between the ethanol- and sucrose-consuming groups.

The mice were tested in the shuttle box 10 to 14 days after drinking the last dose of alcohol. This excluded the possibility that acutely elevated concentrations of alcohol in the blood could have interfered with performance. There was no significant difference between the performance of animals receiving laboratory chow and the liquid diet containing sucrose, so that any difference in performance of mice which had previously ingested ethanol must be attributed to an effect of ethanol per se and not to a dietary deficiency. The significance of learning the shuttle box avoidance tasks has been discussed (*5*). The possibility that impaired performance of ethanol-treated mice is due to decreased activity is unlikely because the intertrial interval responses of all three groups were not significantly different. It is possible that mice drinking ethanol have become less sensitive to the shock stimulus. An impairment in processing painful stimuli by the peripheral or central nervous system in the animals treated with ethanol may possibly explain the observed results (*17*). It is more likely that ethanol or its metabolites impair associative processes of learning in the central nervous system.

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17. This explanation is unlikely because the threshold of shock intensity for all groups was nearly identical. The mean intensity at criterion (five escapes in five trials) was 0.128 ma in the ethanol group, 0.145 ma in the sucrose group, and 0.136 ma in the laboratory chow group.
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Forgetting: Trace Erosion or Retrieval Failure?

Abstract. *A series of lists of random words was presented. Following each list, the subject attempted to recall the words of the list prior to the list just presented. Recall probability for a given word depended on the length of the list in which it was embedded, not on the length of the list intervening between presentation and test. These results indicate that forgetting is a failure in the memory search during retrieval rather than a degradation of the memory trace occurring between presentation and test.*

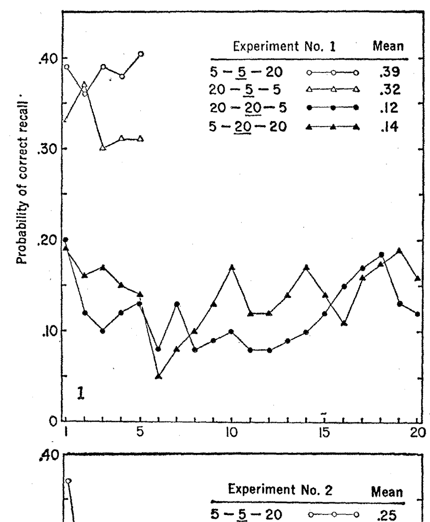
Models of forgetting may be divided into two classes. The first holds that the memory trace formed during presentation is degraded between that moment and the later time of test. In a decay theory, time alone is sufficient to cause degradation of the trace (*1*). An interference theory, however, assumes erosion of the trace to be a function of the kind and amount of stimulation intervening between presentation and test (*2*). It is characteristic of both types of models within this class that forgetting is assumed to be a relatively automatic process, beyond the control of the subject once storage of the trace has occurred.

The second class of models assumes that information is stored permanently and that the memory trace is not eroded between presentation and test. In these models, forgetting occurs as a result of a failure in the retrieval process occurring at the time of the test—the subject fails to find the appropriate memory trace during his search of memory (*3, 4*). These models imply that forgetting is under a degree of control by the subject and that it can be manipulated by the retrieval method employed and by the instructions and cues given at the time of the test. Because many current theories of memory seem to assume both trace degradation and retrieval failure, it is important to determine whether trace erosion is, in fact, a necessary facet of long-term forgetting (*5*).

An appropriate test may be based on the paradigm known as single-trial free recall: a list of common words is presented one at a time; after the presentation, the subject recalls as many of these words as possible, in any order. The data are commonly presented in a serial-position curve, which gives the probability of recall for the word in each presentation position. In typical data (see *6*), the probability of correct recall is almost 1.0 for the last presentation position, drops sharply over the preceding 10 to 15 serial positions (the recency effect), stabilizes at a low level at the intermediate serial positions, and then rises slightly again over the first 3 to 4 serial positions (the primary effect).

Considerable evidence is available to demonstrate that the recency effect is due to retrieval from the short-term store (*7*). Perhaps most striking is the finding (*8*) that a period of 30 seconds of arithmetic following presentation and preceding recall eliminates the recency effect without affecting the probability of correct recall at the earlier serial positions. Thus, the arithmetic serves the purpose of emptying the short-term store of the words in the list, and all subsequent recall originates in the long-term store.

Forgetting from long-term store is seen in this paradigm as the "list-length" effect: the larger is the number of words in the presented list, the smaller is the probability of correct recall for serial positions prior to the recency effect (though the recency effect is unaffected). The trace erosion theories would posit that the items following a given item cause the trace for that item



Figs. 1–3. Probability of recall as a function of serial position for experiments 1, 2, and 3. The conditions are denoted as follows: the first number is the length of the list *preceding* the recalled list, the second number (underlined) is the length of the recalled list; the third number is the length of the *intervening* list. The means listed are averages of all points in the given serial position curves.

to be degraded; in longer lists the number of following items tends to be increased and recall is thereby reduced. Since the recall probability is smaller in longer lists for words that are a fixed number of items before the end of the list, these theories posit that a larger number of items preceding a given item reduces recall. Whether this proactive effect is also the result of trace degradation has not yet been well specified in theories of this type, but we make this assumption for the sake of the argument. A theory of this general type has been applied in detail to free recall (*8*).

An alternative explanation of the list-length effect is provided by a search theory for retrieval (*4*). This theory supposes that long-term store consists of permanently stored images, and retrieval is assumed to be a recursive search process. At the moment of test, the subject defines a "search set" consisting of a number of images appropriately related to the test information. Successive random draws of one image at a time are then made from this search set. The probability of examining an image is its strength divided by the summed strengths of all the items in the search set, whereas the probability of recovering the information contained in an examined image will depend on its strength alone. Retrieval will terminate when the available response time is gone or when the subject decides that further search will not be fruitful.

In a context of single-trial free recall, this theory assumes that the search set consists primarily of images of words in the just presented list. If one assumes that the number of draws until the termination of retrieval is relatively insensitive to the size of the search set, then the list-length effect is predicted. That is, the larger the number of images in a search set, the smaller will be the probability of examining a given image during the search. A quantitative model embodying these assumptions was applied to a variety of experiments in free recall, many of which employed lists of varying length (*4*). The impressive fit of the predictions to the data demonstrated the viability of the approach.

It thus appears that both a trace degradation theory and a retrieval theory are capable of dealing with list-length effects in free recall, despite radically different approaches. This result is not surprising when one notes that the length of the list to be recalled and the number of items intervening between presentation and test are badly confounded variables in the paradigm of single-trial free recall. One change in the procedure will eliminate this confusion. After the presentation of each list, the subject attempts to recall not the list just presented but, instead, the list presented just before the last list. It then becomes possible to vary independently the length of the list being recalled and the length of the list intervening between presentation and recall. This procedure will be denoted as "delayed free recall"; it forms the basis for the experiments reported here. A degrading trace theory would predict that probability of recall of a given word will be dependent on the length of the list intervening between presentation and recall. A search theory, if it can be assumed that the search set is more or less restricted to members of the list to be recalled, predicts that recall probability should be dependent on the size of the list in which the word to be recalled is embedded.

Experiment 1. The subjects were undergraduates at the University of Indiana. Each subject was presented with 20 lists of words; each list was presented visually one word at a time, and no word was ever repeated. The words were chosen from a master list of 400 frequently used English words from four to six letters in length. This master list was permuted for each subject, so that each subject received the words in a new random order. The subject's responses were typed.

Two groups of subjects were used in experiment 1. The 20 subjects of group 1 received lists of the following lengths, in the order given:

5-20-20-5-5-20-20-5-5-20-
20-5-5-20-20-5-5-20-20-5

The 22 subjects of group 2 received the following order of list lengths:

20-5-5-20-20-5-5-20-20-5-
5-20-20-5-5-20-20-5-5-20

The subjects were instructed to attempt to recall in any order all of the words from the list seen just prior to the one presented. The attempt to recall was made after each presented list except the first list of the session. Each word was presented for 1 second; 1 minute was allowed for recall after a list had been presented. After presentation of list 1, the subject simply waited until the recall period terminated. The subjects knew that list lengths would vary but did not know what lengths would be involved, and they did not know before a list presentation whether a long or short list would be forthcoming.

There are four primary conditions in this within-subject design, denoted 5-5-20, 20-5-5, 20-20-5, 5-20-20. The underlined number gives the length of the list to be recalled, the first number gives the length of the list preceding the list to be recalled, and the third number gives the length of the list intervening between presentation and recall. The results can be seen in the form of curves plotted for serial position and probability of correct recall for each of these conditions. Recall of the first list presented in each session is not included in the data, since this list was not followed by active recall. The data from group 1 and group 2 were not distinguishable; therefore, these data were combined, and the results are given in Fig. 1. The mean probability of correct recall averaged over all serial positions is also shown in the figure. The results are absolutely clear-cut: the length of the list being recalled determines the level of recall, and the length of the list intervening between presentation and recall has no effect (if anything, a longer intervening list results in higher recall).

Experiment 2. A second experiment was carried out to eliminate the possibility of rehearsal occurring after the conclusion of retrieval and before the presentation of the next list. The procedure was identical in all respects to the procedure for experiment 1 with the exception of one factor: the subject pressed a button during his recall period when he felt that he could not successfully recall any more words. This response caused the presentation of the next list to begin at once. In this experiment there were 19 subjects in group 1 and 17 subjects in group 2.

Again there were no differences between groups 1 and 2, and therefore these data were combined (see Fig. 2). The results are readily apparent and confirm the results of experiment 1. The only effect of the altered procedure was a slight lowering of overall performance and the elimination of any inverse effect of intervening list size. Intervening list size now had no effect whatever.

Experiment 3. A final experiment was made to eliminate the possibility that the results were affected by the size of the list that preceded the list to be recalled. The procedure was identical to that for experiment 2 in all respects except one: the sequence of list lengths was altered. All 33 subjects received the same sequence of list lengths as follows:

20-5-5-20-5-20-20-5-20-5-
5-20-5-20-20-5-20-20-5-20

There are six primary conditions for experiment 3. These are denoted in the manner used previously as 5-5-20, 20-5-20, 20-5-5, 5-20-5, 20-20-5, and 5-20-20. The two unambiguous comparisons are 5-5-20 versus 5-20-5, and 20-5-20 versus 20-20-5. The results are given in Fig. 3 and, once again, are clear-cut: performance levels are dependent on the length of the list being recalled and are not dependent on the length of the list preceding the recalled list, or on the length of the list following the recalled list.

These three experiments leave no doubt that recall is dependent on the length of the recalled list and independent of the length of the intervening list. It may be concluded that retrieval factors in forgetting are considerably more important than factors dependent on a degrading trace.

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