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Alcoholic intoxication and memory storage dynamics

WAYNE A. WICKELGREN
University of Oregon, Eugene, Oregon 97403

Strength retention functions were obtained for English words from 2 min to 50 min within a continuous recognition memory session and from 1 to 14 days subsequent to the session, with subjects being sober or moderately intoxicated. A small, but significant, decrement was obtained in memory performance under alcoholic intoxication. However, there was no difference in forgetting rate either within the continuous session or over the subsequent 1- to 14-day period. Single-trace fragility theory provided an excellent fit to the data. The entire effect of alcoholic intoxication was on degree of learning with no effect on the form of the retention function or rate of forgetting. No state-dependent retrieval effects were obtained. White noise during learning and/or retrieval had no effect on acquisition, storage, or retrieval.

For a long time, there has been a phenomenological claim that alcoholic intoxication depresses memory performance. The most extreme form of this impairment being the so-called alcoholic "blackout" in which subjects have performed relatively complex cognitive tasks during a period of extreme intoxication, but have no memory at some later time for the events taking place during this period. Blackout is not consistently produced by any known set of conditions, even among heavily drinking alcoholics, and at this point we have little idea concerning what produces it. However, it appears that alcoholic subjects who later experience blackout tend overwhelmingly to be those who had impaired memory performance during the period of alcoholic intoxication itself (Goodwin, Othmer, Halikas, & Freemon, 1970; Tamerin, Weiner, Poppen, Steinglass, & Mendelson, 1971). This indicates that blackout is at least partly an acquisition and/or storage phenomenon observable during the period of alcoholic intoxication itself, and not entirely a state-dependent retrieval phenomenon.

It is not known whether there is any continuity between the severe memory impairment of blackout that occasionally accompanies heavy drinking and the modest memory impairment alleged to accompany more moderate (social) drinking. Impairments on cognitive tasks under moderate alcoholic intoxication have not always been obtained (see Mello, 1971a, b). However, a number of studies have obtained a negative effect of alcohol on memory performance (Carpenter & Ross, 1965; Goodwin, Powell, Bremer, Hoine & Stern, 1969; Ryback, Weinert & Fozard, 1970; Tamerin et al., 1971). As Mello (1972a, b) has pointed out, there is some indication that there may be no direct effect of alcohol on memory acquisition and storage, but only an indirect effect on memory through the effects on attention, arousal, and motivation in general. If subjects under alcoholic intoxication are motivated to perform the task, and efforts are made to insure attention to the material to be remembered at the time of learning, then it is possible that there are no negative effects of alcohol on memory acquisition and storage. This is a rather difficult question to answer in the absence of some independent measure of attention, arousal, and task motivation. Furthermore, it may be that, at high levels of intoxication, there is no experimental procedure that will achieve a level of attention, arousal, and motivation equivalent to that obtained in the sober state.

A question largely independent of the direct vs. mediated effects of alcohol on memory is the locus of that effect in acquisition, storage, or retrieval. Does alcohol reduce the level of learning? Does it increase the decay rate or otherwise change the forgetting function? Does it affect the set of cues available during retrieval so that memories established under alcohol are most retrievable under alcohol, while memories learned while sober are most retrievable while sober? This latter hypothesis has frequently been referred to as "state-dependent learning," but of course it is the similarity of the cues present during the learning and retrieval situation that is responsible for the phenomenon, so "state-dependent retrieval" seems like a more appropriate term.

State-dependent retrieval produced by alcohol has frequently been obtained in both animals and humans, especially under moderate to heavy doses of alcohol (see Overton, 1972 for a complete review and discussion plus a recent paper by Weingartner & Faillace, 1971, not included in that review). As Overton points out, it is quite clear that total dissociation is not produced by moderate drinking. However, it is important to note that state-dependent retrieval has only been observed with recall measures of memory. Recognition measures of memory storage are considered to be independent of many types of retrieval interference, and recognition also appears to be free from state-dependent retrieval effects with both alcoholic intoxication (Goodwin et al., 1969), and thiopental sedation (Osborne, Bunker,

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Cooper, Frank, & Hilgard, 1967). Furthermore, even with recall, it is quite clear that there are frequently negative effects of alcohol on acquisition and/or storage, over and beyond the state-dependent retrieval effects (Goodwin et al., 1969; Overton, 1972).

In deciding the degree to which alcohol adversely affects either the acquisition or storage phases of memory, several investigators have made the typical mistake of assuming that because memory is close to perfect immediately after learning, the initial level of acquisition of the memory trace is equivalent for both sober and intoxicated groups (e.g., Ryback et al., 1970; Tamerin et al., 1971). There is no reason to believe that the strength of the memory trace is proportional to, or even linear with, the probability of correct recall or recognition, and there is substantial reason to believe that it is not. For example, many different degrees of overlearning produce probabilities of correct performance close to 100% at short retention intervals, but overlearning greatly facilitates performance at longer retention intervals. A parsimonious account of such effects is provided by a strength theory of memory in which small differences in probability-correct close to 100% are associated with very large differences in underlying memory trace strength (e.g., Wickelgren & Norman, 1966; Wickelgren, 1972, 1974).

According to the single-trace fragility theory of Wickelgren (1974), the form of the retention function is:

$$d = \lambda t^{-\psi} e^{-\pi t} \qquad (1)$$

where d represents the strength of the memory trace at retention interval t (sec), λ represents the degree of learning (initial strength of the trace), ψ represents the rate parameter for the time-decay process, and π represents the rate parameter for the interference process. Actually, the theory described in Wickelgren (1974) predicted a slightly more complex form of Equation 1, which is approximately equivalent to this simpler form for the retention intervals of the present experiment. For the purposes of the present study and the data reported in Wickelgren (1974), the difference between the two equations is negligible, and the same conclusions would be reached with either form.

The purpose of the present study is to determine whether the theoretical function proposed by a single-trace fragility theory (Wickelgren, 1974) provides a good fit to the data for material learned while sober and while intoxicated over a range of retention intervals from 2 min to 2 weeks, or whether alcoholic intoxication changes the form of the retention function. If both conditions produce a retention function of the same form, then the subsidiary questions are whether alcohol affects degree of learning, decay rate, or both.

Recognition memory is studied because the focus is on the acquisition and storage effects of alcohol rather than on retrieval effects (state-dependent or otherwise).

Finally, there has been some evidence that arousal is beneficial for long-term memory, and that white noise administered simultaneously with a learning trial increases arousal and also facilitates memory (Berlyne, Borsa, Craw, Gelman, & Mandell, 1965; Berlyne, Borsa, Hamacher, & Koenig, 1966; Uehling & Sprinkle, 1968). Another purpose of the present study was to study the effects of noise during both acquisition and retrieval and determine whether noise-induced arousal counteracted any depressant effects of alcohol on acquisition, storage, or retrieval.

METHOD

Subjects

The ten subjects used in the experiment were paid volunteers recruited from the University of Oregon Student Employment Office. Subjects were selected with the following conditions: each subject had to be 21 years of age and be able to get back from the alcohol sessions without driving a vehicle. Subjects also had to weigh between 100 and 160 pounds and have had previous experience consuming a quantity of alcohol equivalent to that supplied in the experiment, without serious adverse effects.

Procedure

Subjects were instructed not to eat for 2 h prior to the experimental session. During the first 20 min of an experimental session, subjects in the alcohol condition consumed a quantity of alcohol equal to .83 ml of alcohol per kilogram of body weight mixed with 5 oz of orange juice plus ice in two glasses. For a 160-lb individual, this dose is equal to 5 oz of 80 proof vodka. Subjects in the control condition consumed 10 oz of orange juice plus ice in two glasses during the same 20-min period. The next 2 h and 20 min were devoted to the continuous recognition memory experiment, and the last 20 min of the session were devoted to "sobering up" (consuming two to three aspirins, along with ginger ale, club soda, coffee, and/or a caffeine pill, as desired by the subject).

Subjectively, subjects were moderately inebriated at the beginning of the session and were still quite intoxicated by the end of the session. No measurements of blood alcohol level were taken, but based on Ideström and Cadenius (1968), blood alcohol concentration rises rapidly and should have reached maximum in about 30 min, maintained that maximum level pretty well for the next hour, and declined to about 75% of maximum by the end of the session. Researchers inclined toward a more compulsive approach to the measurement of blood alcohol level should be aware of the following: First, the convenient Breathalyzer® measurements are highly inaccurate in assessing blood alcohol level (Spector, 1970). Second, the psychological effects of alcohol are not simple functions of blood alcohol concentration, differing, for example, on the ascending and descending limb of the blood alcohol curve (e.g., Jones & Vega, 1972).

In the continuous recognition memory session, subjects read an English word and decided whether or not it had been presented previously, also giving their confidence in this decision on a six-point rating scale. The rate of presentation was 4 sec per word. Subjects were instructed not to rehearse (think of) previously presented words, concentrating only on the current word. Subjects were also instructed to base their decisions on the immediate familiarity of the presented word, without attempting to use any more complex retrieval strategies. White noise was presented with half of the words in the session, and no noise accompanied the other half of the words. The white noise was presented through earphones, lasted for 4 sec, and was about 70 dB in intensity (no measurement was made).

Subjects were also brought back for six subsequent test sessions to test longer-term retention ranging from 1 to 14 days following the learning session. In each subsequent test session, there was a random mixture of previously presented words with an equal number of new words, with half of the old words and half of the new words being tested in noise and half in quiet. Subjects were always sober in the subsequent test sessions, no matter whether they had learned the words sober or intoxicated.

Materials

The words were selected from a population of 9,915 most frequent nouns, verbs, adjectives, and adverbs, according to the Thorndike-Lorge (1944) word count. Proper nouns were excluded from the population, and an attempt was made to include only one word-class or word-case variation of the same stem (e.g., commit, commitment). Words were presented through the window of a Lafayette Instrument Company memory drum that uses computer output paper, and subjects punched their own responses using a Wright line manual card punch.

Design

The trials on which an item was presented for the first time constitute the "new" condition to which the correct response is "no." During the continuous session, there were six different "old" conditions (trials on which an item had appeared previously at one of six different delays). The delays were 2, 4, 7, 15, 30, and 50 min. The assignment of conditions and words to trials was accomplished by a computer which attempted to equate for practice effects in both learning and retention testing by the following means. Trials 1 to 50 were considered practice. Subjects' responses during the first 50 trials were not scored, and no word which was presented during the first 50 trials was tested after the first 50 trials in the main portion of the continuous session. During the main portion of 1800 trials (Trials 51 to 1850), the learning trials for all of the delay conditions appeared approximately an equal number of times, but tests of words that were initially presented during the last portion of this period were allowed to extend into the last block of 250 trials (1851 to 2100). This procedure equates exactly for practice/fatigue effects in learning, and equates almost exactly for practice/fatigue effects in retrieval during the continuous session.

Some words were not tested during the continuous session, but were tested at one of six subsequent test sessions, with retention intervals at 1, 2, 4, 7, 10, and 14 days. Altogether, there were 12 delay conditions crossed with two noise vs. quiet learning conditions crossed with two noise vs. quiet test conditions. This produced 48 old-item conditions per replication. There were approximately 25 replications of each condition per set, and there were two alcohol sets and two sober sets for each subject. A set was run over a 2-week period (include the subsequent test sessions), and then the next set was begun for the same subject over the following 2-week period, and so on, until all four sets had been run. Prior to beginning the four experimental sets, all subjects were given an initial practice continuous-recognition memory set under the sober condition. No words were repeated across these five sets, except for deliberate tests of previously presented words within a set. Thus, there was a basic sample size of 50 trials for each subject for each of the 48 old-item conditions, and a sample size of over 600 trials in the new-item noise condition and over 600 trials in the new-item quiet condition per subject. Following the practice set, the order of sequencing alcohol and sober conditions for five of the subjects was alcohol, sober, sober, alcohol, and for the other five subjects, was sober, alcohol, alcohol, sober.

Analysis

Using the statistical decision methods described in Wickelgren (1972), memory strength discriminability values (d_a) were obtained from memory operating characteristics that plotted each old-item condition against the appropriate new-item condition. The d_a values are unbiased (interval-scale) measures of memory strength discriminability, similar to d′ values, but with lower variance. Retention functions derived in this way for each subject were averaged logarithmically to obtain average retention functions for each condition. According to the theory of memory dynamics proposed by Wickelgren (1974) to be tested in this paper, logarithmic averaging of individual d_a values is the appropriate method of averaging, since that method will not distort the form of the retention function in going from individual subjects to group averages.

RESULTS AND DISCUSSION

The presence of noise in both acquisition and retrieval had no systematic effect on either the strength of the memory trace (degree of learning and retrieval) or on the rate of forgetting. Therefore, all of the subsequent data are pooled over the noise variable. In some sense, this constitutes a failure to replicate previous studies of the effects of noise-induced arousal on memory. There are at least two explanations for the effect. First, recognition was used in the present study, rather than recall, but it is doubtful that this is the critical variable. Second, the noise was switched on and off as rapidly as every 4 sec. This may have led to a complete saturation of the effects of noise on arousal. If the arousal response to noise is sufficiently slow in relation to the 4-sec period, then there will be essentially no manipulation of the state of arousal. Very likely, this is what happened, and I think the present results are not contradictory to the previous findings concerning the effects of noise-induced arousal on memory.

Although the effect was not large, a statistically significant decrement in memory was obtained under the condition of alcoholic intoxication compared to sobriety. This was true both during the continuous session when subjects were tested in the same state (intoxicated or sober) under which they had learned the material and was also true in subsequent sessions when all subjects were tested sober whether they learned under conditions of intoxication or sobriety. The average retention functions for both sober and alcohol conditions are presented in Figure 1, along with the (least squares) best-fitting theoretical lines derived from Equation 1.

As is evident from Figure 1, Equation 1 provides an extremely good fit to the data under both sober and alcohol conditions. The good fit of Equation 1 is particularly remarkable considering the enormous range on the independent variable, amounting to a factor of 10^4. The good fit to the data both during the session and over retention intervals filled with normal daily activities (including sleep) is evidence for the assumption made in Wickelgren (1974) that most of the decay (during the continuous session and subsequently) is due to the time decay process, with relatively little effect of the interference process. The fact that the interference

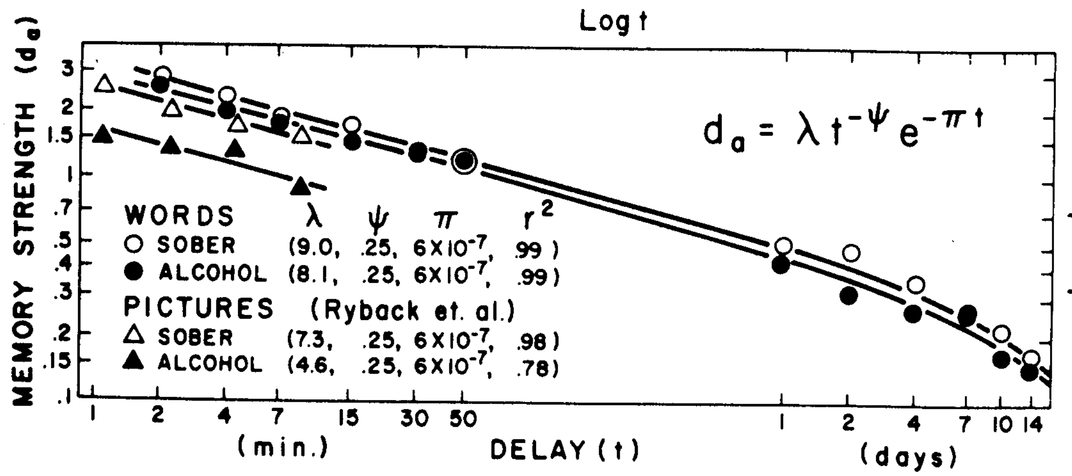

Figure 1. Strength retention functions under sober and intoxicated conditions for words (present study) and pictures (Ryback, Weinert, & Fozard, 1970).

parameter (π) was so low supports this interpretation, along with the substantial degree of linearity of the retention function on the log-log plot of Figure 1. It should be noted that even a moderately large difference in the value of the interference parameter for the continuous session vs. normal daily activities would not be noticeable in the present data, because at such a low absolute level of π, the interference process has very little effect over a 50-min retention interval. Over a period of a week or two, with $\pi = 6 \times 10^{-7}$, the interference process does result in a slight deviation from the straight line on a log-log plot (as predicted by the time decay process alone), precisely as observed in the present data, namely, a slight downward curvature at long delays.

Since the same form of the retention function provided a good fit under both sober and alcohol conditions, it is relevant to inquire whether the effect of alcohol was on learning, time-decay rate, or interference. The entire difference between the two conditions was most parsimoniously accounted for in terms of a different initial degree of learning, with no evidence for an effect of alcohol on either the time-decay rate or the interference process. The single-trace theory with common decay rate and interference parameters for sober and alcohol conditions accounted for over 99% of the variance in both conditions. The parameter estimates are also shown in Figure 1.

Furthermore, it should be noted that in agreement with the single-trace theory of memory described in Wickelgren (1974), there is, once again, no evidence for the existence of two dynamically different traces, short-term and long-term memory. Nor is there evidence of any differential effect of alcohol on short-term vs. long-term retention through some hypothetical conversion from short-term to long-term or any other consolidation process.

Furthermore, the present study replicates Goodwin et al. (1969) in finding no evidence for state-dependent retrieval using the recognition measure. The evidence for this is that there is no greater difference between the retention functions during the later test sessions than during the initial continuous session. If state-dependent retrieval were a significant factor, one would expect the retention function for the alcohol condition to be farther below that for the sober condition during the later sessions than during the continuous session. The failure to find such an effect argues that state-dependent retrieval played no significant role in the present experiment, in agreement with previous studies using recognition memory. However, at the lower dose used in the present experiment, there was less reason to expect state-dependent retrieval in the first place.

Figure 1 also displays the average strength retention functions obtained under sober and intoxicated conditions by Ryback et al. (1970) transformed from probabilities corrected for guessing into measures of memory strength. The lines are best-fitting theoretical predictions for single-trace fragility theory, under the assumption that the only difference between the conditions is in initial degree of learning. Note that the theory provides a good fit to the data, but since retention was assessed over such a limited dynamic range, this is a finding of only modest significance. However, it is of some significance that the same decay rate parameters provided a good fit for both the present study of recognition memory for words and the Ryback et al. study of recognition memory for pictures. Finally, this replotting of the data of Ryback et al. (1970) directly contradicts the conclusion one might draw from their discussion that alcohol affected storage, rather than just initial degree of learning. Furthermore, there is no basis in the data of Ryback et al. for any distinction between two, let alone three, memory traces or processes. A very parsimonious account for both the Ryback et al. data and the present data is that a single memory trace is established with somewhat greater initial strength under the sober condition than under the alcohol condition.

One final feature of the data deserves some comment. Ryback et al. (1970) obtained a much larger difference in initial degree of learning between alcohol and sober conditions than was obtained in the present study. The smaller difference in degree of learning obtained in the present study is most likely accounted for by some combination of the following three factors: First, a somewhat lower dose of alcohol was employed in the present study than in the Ryback et al. study (.83 cc alcohol/kg vs. 1.2 cc/alcohol/kg). Second, subjects were more effectively forced to attend to the learning material in the present study than in the Ryback et al. study. In the present study, subjects were forced to make a decision regarding each item as to whether or not it had appeared previously. By contrast, in Ryback et al., presentation of pictures to be learned was alternated with forced-choice tests. This means that the subjects were not forced to attend to the pictures to be learned in Ryback et al., possibly leading to differences in attention between the sober and intoxicated conditions. Third, the noise used in the present study may have generally facilitated arousal, counteracting the effects of the alcohol, though not differentially for noise vs. quiet trials.

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