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EFFECTS OF ETHANOL ON REINFORCED VARIATIONS AND REPETITIONS BY RATS UNDER A MULTIPLE SCHEDULE

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Response sequences emitted by five Long-Evans rats were reinforced under a two-component multiple schedule. In the REPEAT component, food pellets were contingent upon completion of a left-left-right-right (LLRR) sequence on two levers. In the VARY component, pellets were contingent upon variable sequences (i.e., a sequence was reinforced only if it differed from each of the previous five sequences). The rats learned to emit LLRR sequences in the REPEAT component and variable sequences in VARY. Intraperitoneal injections of ethanol (1.25, 1.75, and 2.25 g/kg) significantly increased sequence variability in REPEAT, thereby lowering reinforcement probability, but had little effect on sequence variability in the VARY component. These results extend previous findings that alcohol impairs the performance of reinforced repetitions but not of reinforced variations in response sequences.

Key words: behavioral variability, response sequences, repeated sequences, response chains, ethanol, alcohol, multiple schedule, rats

Reinforcers control response variability. Supporting evidence comes from studies in which responses of rats were reinforced for generating variable sequences on two levers (Bryant & Church, 1974), dolphins for sequences of behaviors not previously observed by the experimenters (Pryor, Haag, & O'Reilly, 1969), pigeons for interresponse times that occurred least frequently (Blough, 1966), children for novel drawings and constructions (Holman, Goetz, & Baer, 1977), and adults for generating random numbers (Neuringer, 1986).

Page and Neuringer (1985) analyzed the control by reinforcement over response sequence variability of pigeons. A trial consisted of eight pecks distributed over two keys. The trial ended with food if the current sequence of eight left and right responses differed from that in each of the last n trials, with n referred to as the "lag." When $n = 5$, for example, the current sequence had to differ from each of the last five sequences. Variability increased in response to increasing lag requirements; that is, sequence variability changed with the reinforcement contingencies (see also Machado, 1989), and contingent reinforcement was necessary for high levels of variability. Page and Neuringer also found that, as with other operant dimensions, variability was controlled by discriminative stimuli. Because behavioral variability depended on reinforcers contingent upon the variability, and because the levels of variability came under stimulus control, Page and Neuringer suggested that variability was an operant dimension, controlled in ways analogous to such other operant dimensions as response rate, probability, force, location, and class. (For further evidence, see Crow, 1988; Machado, 1989; Morris, 1987; Neuringer, 1986; van Hest, van Haaren, & van de Poll, 1989.)

McElroy and Neuringer (in press) extended this research to compare the effects of alcohol on reinforced variability and reinforced repetition. One group of rats, the VARY group, learned to emit four presses on two levers per trial, with the current sequence reinforced if it differed from each of the last five sequences, or Lag 5. For the REPEAT group, a single sequence was reinforced, namely left-left-right-right (LLRR), a pattern chosen because the number of repetitions and alternations, given perfect LLRR performance, equals that to be

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expected from an ideal random generator under VARY contingencies. McElroy and Neuringer found that alcohol significantly increased variability under the REPEAT contingencies, thereby causing a significant decrement in reinforcement frequencies. On the other hand, alcohol had little or no effect under the VARY contingencies. Thus, when a repeated sequence was required for reinforcement, alcohol had detrimental effects, but when variable sequences were required, there was little effect.

The present study extends this research in two potentially important ways. First, we used a multiple schedule in which VARY and REPEAT components alternated throughout each session, thereby permitting within-subject comparisons. Second, in the study of McElroy and Neuringer (in press), four responses constituted a trial for the VARY group, but errors immediately terminated trials for the REPEAT group. If the first response in a REPEAT trial was on the incorrect right lever, for example, that trial terminated immediately. The procedural difference between VARY and REPEAT groups was due to McElroy and Neuringer's difficulty in training and maintaining high REPEAT success rates. The present study used a slow shaping procedure to generate relatively accurate REPEAT performances before presenting the VARY contingencies. Under a multiple schedule, trials in each of the two components were four responses in length. In the VARY component, the fourth response was followed by a food pellet if the sequence differed from each of the preceding five VARY sequences and was followed by timeout whenever the contingency was not met. In REPEAT the fourth response in the trial was followed by food if the sequence had been LLRR and by timeout for any other sequence. Constant and equal sequence lengths permit comparisons and analyses not possible in the study of McElroy and Neuringer. The basic questions are whether and how alcohol affects reinforced variability versus reinforced repetition.

METHOD

Subjects

Five experimentally naive male Long-Evans rats, approximately 12 months old at the beginning of the experiment and weighing between 220 and 320 g, were housed in individual stainless steel cages (20 by 20 by 25 cm) and maintained on a 22-hr food deprivation cycle with 1 hr of free access to food per day following experimental sessions. Free access to water was provided except during these sessions.

Apparatus

Five modified Gerbrands operant chambers (27 by 28 by 30 cm) had ceiling, back, and front walls constructed of Plexiglas and side walls of metal. One side wall contained two response levers, 5 cm above the floor and 9 cm apart; centered between them was a pellet tray, 3 cm above the floor, into which were dispensed 45-mg Noyes food pellets. The opposite side wall contained three pigeon keys (not used in the present experiment except for illumination), located 9.5 cm above the floor, that could be illuminated by white 24-V bulbs and that were used as discriminative stimuli, as will be described below. On top of the ceiling was another 24-V clear bulb, also used as a discriminative stimulus. A speaker, located behind the wall containing the levers, provided auditory discriminative stimuli as well. The chambers were housed in sound- and light-attenuating outer boxes containing one-way mirrors for observation. Macintosh® computers were interfaced through Metaresearch Bench Tops® to the experimental chambers, and programs were written in True Basic.

Procedure

Subjects were trained to respond on each of the two levers and then given fixed-ratio (FR) 2 contingencies, with the effective lever alternating after each reinforcement so that responses occurred approximately equally on the two levers.

Preliminary REPEAT training. Page and Neuringer (1985) and McElroy and Neuringer (in press) reported that pigeons, in one case, and rats, in the other, had more difficulty learning to respond repetitively (e.g., LLRR) than variably. Therefore, initial training of the LLRR sequence was provided in six stages. The chamber was illuminated by the three pigeon keylights. In Stages 1 and 2 (one session), a reinforcement followed two consecutive right responses, or RR, and then LRR. Incorrect L responses led to a 3-s timeout during which the chamber was dark and a 1200-

Hz intermittent tone was sounded. Responses during timeout reset the interval so that a 3-s period without responding was required before the next trial. In Stage 3 (approximately five sessions), two consecutive left responses, followed by two consecutive right responses, were required. Perseverations on the left lever (after the first two correct responses) or right lever (after reinforcement) had no consequence, but a timeout was given if a right response followed the initial left, or if a left response followed the first correct right response. Stage 4 (one session) was similar to Stage 3 except that right responses following reinforcement also led to timeout. In Stage 5 (approximately 12 sessions), an LLRR sequence was required for reinforcement with all errors immediately producing a 3-s timeout. Stage 6 (approximately 11 sessions) again required the complete LLRR sequence for reinforcement but timeout now followed only the fourth response in the sequence. In this final stage, each trial consisted of exactly four responses: If LLRR, the trial terminated with food; if any of the other 15 possible four-response sequences, the trial terminated with a 3-s timeout. During these preliminary training phases, each response was followed by a 0.15-s interresponse interval (IRI) during which a 900-Hz tone sounded and the three rear keylights were darkened. Responses during the IRI reset the interval and were not counted towards the LLRR contingency. Thus, at the beginning of multiple schedule training, the REPEAT contingencies were as follows: Each trial consisted of four responses, with a 0.15-s IRI following each of the first three responses. If the fourth response completed a LLRR sequence, it was followed immediately by food; if the fourth response completed any of the other 15 possible patterns, it was followed immediately by a 3-s timeout. A new trial immediately followed timeout or reinforcement.

Multiple schedule. Training under a multiple schedule followed the REPEAT training described above.

1. REPEAT component. During the REPEAT component, the three rear keys were illuminated, the overhead light was off, a 900-Hz tone followed each of the four effective responses, and reinforcement was contingent upon the LLRR sequence, as just described. Immediately following the 10th reinforcement, all lights in the chamber were darkened for a 10-s intercomponent interval (ICI) during which responses were not counted toward the REPEAT or VARY contingencies. If no response occurred within the last 3 s of the ICI, the VARY component was presented. Responses during the last 3 s of ICI reset the 3-s interval, assuring at least 3 s without a response before a component change.

2. VARY component. VARY trials were also four responses in length, with a 0.15-s IRI following each of the first three responses and a 3-s timeout for sequences that did not meet the variability contingencies. Reinforcement depended on a variability, Lag 5, contingency as follows. There are 16 possible four-response sequences of left and right (2^4). If the current trial contained a sequence different from the sequences emitted during each of the last five trials, the current trial ended with food. If the current trial repeated any one of the last five sequences, the trial ended with the 3-s timeout. Response sequences in the VARY components were compared only to previous VARY sequences. For the first sequence in a VARY component, for example, a pellet was provided only if the sequence differed from each of the last five sequences in the previous VARY component (without regard to behavior in the intervening REPEAT component). Furthermore, at the very beginning of a session, the first five VARY trials were compared with the last VARY trials in the preceding session. During VARY, the three rear keys were dark, the overhead light was on, and a 2400-Hz tone followed each of the four effective responses in the trial. In all other ways, the parameters and contingencies were identical to those under REPEAT. As for REPEAT, the 10-s ICI followed completion of the 10th VARY trial.

Note that no VARY training was given prior to presentation of this multiple schedule. Note also that the light and tone stimuli designating VARY and REPEAT components were as described above for 4 subjects but were reversed for 1. We detected no effects of the particular stimuli.

REPEAT and VARY components alternated until 200 pellets were obtained or 90 min had elapsed, whichever occurred first. The first three sessions of training began with the REPEAT component (because the subjects had received prior training only with the RE-

PEAT contingencies), but thereafter every other session began with REPEAT and every intervening session with VARY. After performances under this multiple REPEAT–VARY schedule had become stable, so that number of trials per component and percent of reinforced sequences in each component did not fluctuate by more than 10% (between 7 and 28 sessions), the following changes were made: The components changed after 30 trials, the approximate number of trials required for 10 reinforcements under the previous procedure; the IRI was increased to 0.5 s in both components (with responses during the IRI resetting that interval); and the initial component in a session changed after every two sessions, that is, two sessions in a row began with VARY, then two with REPEAT, and so forth, this in preparation for the drug-testing procedures to follow. Approximately 38 sessions were presented under these final multiple REPEAT–VARY contingencies.

Assessing the Effects of Alcohol

Injection procedure. Intraperitoneal (IP) injections of ethanol or saline were administered 13 min before the session (as in Devenport, 1983).

Saline sessions. Subjects received two sessions following injections of 2 mL of a 0.9% saline solution. Each of these saline-injection sessions was preceded by a no-injection control session. Average performances during the two saline sessions were compared with the averages during the two control sessions.

Ethanol sessions. One session was given with a 0.75 g/kg dose of ethanol to acclimate the subjects and was followed by four sessions each with 1.25, 1.75, and 2.25 g/kg doses, in that order. The ethanol solution was composed of 95% ethanol and 0.9% saline in a 10% w/v concentration.

Control sessions. One no-injection control session preceded each session with ethanol administration. Two additional no-injection control sessions were given between the last 1.75 g/kg and the first 2.25 g/kg sessions. Thus, for each dose of ethanol, there were four sessions of drug injection, with each being preceded by at least one no-injection control session.

Data Analyses

Percentages of reinforced sequences were calculated by dividing the number of correct sequences—those which met the schedule contingencies and were therefore reinforced—by total sequences for each session. This was done separately for the VARY and the REPEAT components; that is, reinforced VARY sequences were divided by total VARY sequences and reinforced REPEAT sequences by total REPEAT sequences.

An index of overall sequence variability, or U value, was also calculated (Miller & Frick, 1949; Page & Neuringer, 1985). If each of the 16 possible sequences were emitted equally often in a session, U would equal 1.0. If only one of these sequences were emitted throughout the session, U would equal 0.0. As for percentage reinforced, U values were calculated separately for VARY and REPEAT components in each session. For both percentage reinforced and U-value calculations, in the infrequent cases in which fewer than 10 trials were completed in either of the components, that session's data were excluded from statistical analyses and graphs. For each subject, percentage reinforced and U-value averages were calculated across the four injections at each ethanol dose as well as the two sessions of saline, the latter being used as the zero dose in the figures and statistical analyses. Repeated measures, two-factor analyses of variance (VARY vs. REPEAT Contingencies × 4 Drug Doses; CLR ANOVA, Clear Lake Research, 1985) were performed.

RESULTS

Figure 1 shows the percentages of reinforced sequences in each component as a function of drug dose. The 2 × 4 repeated measures ANOVA showed significant main and interaction effects: (a) The overall percentage of reinforced sequences in the VARY component was higher than in REPEAT, $F(1, 4) = 16.148$, $p = .016$; (b) percentage of reinforced sequences decreased with increasing drug doses, $F(3, 12) = 28.742$, $p = .000$; and (c) VARY and REPEAT performances showed different dose/response effects (i.e., the interaction was significant, $F[3, 12] = 7.904$, $p = .004$). One-way repeated measures ANOVAs on the four doses showed a significant decrease in percentage of reinforced sequences as a function of dose in the REPEAT component, $F(3, 12) = 21.497$, $p = .000$, but not in VARY, $F(3, 12) = 1.186$. Both VARY and REPEAT performances could have been influenced by the

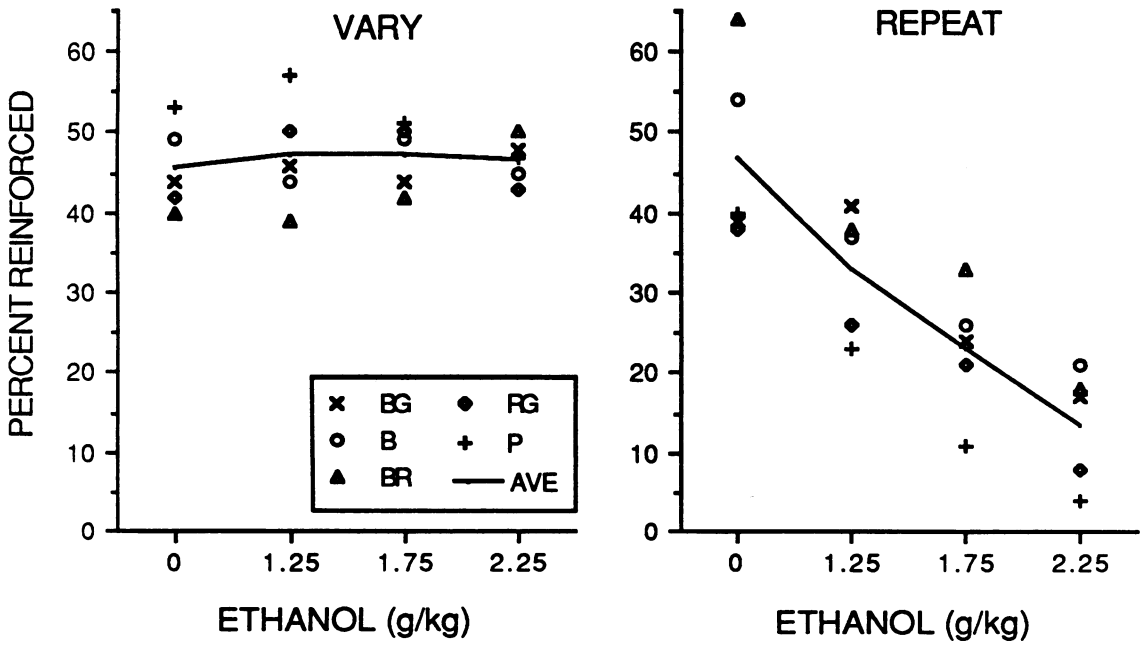

Fig. 1. Average percentages of reinforced, or correct, sequences as a function of ethanol dosage for each of 5 subjects. Each data point is an average of four sessions (except if a session contained fewer than 10 trials; see Data Analysis). Performances in the VARY component are shown to the left and in REPEAT to the right. The lines connect averages of the 5 subjects.

systematic increase in doses across blocks of sessions, a possibility that must be addressed by future research. However, both groups experienced the same drug procedure, and the main finding was that alcohol impaired performances when a repeated sequence was required for reinforcement but not when variable sequences were required.

That the injection procedure itself did not influence performance is seen by comparing the two saline injection sessions with the two preceding no-injection control sessions. Under REPEAT, 47% of sequences were correct after saline injections, and this did not differ significantly from the 48% average during the two control sessions, $t(4) = 0.605$. Similarly, under VARY, there was no significant difference between saline sessions, 46%, and control, 43%, $t(4) = 0.811$. Furthermore, percentage of reinforced sequences under saline did not differ between the two components, $t(4) = 0.221$, nor was there a difference during the average of all no-injection control sessions, $t(4) = 1.24$. Thus baseline performances were similar across components.

The decrease in percentage of reinforced REPEAT sequences could have been caused by a general increase in sequence variability or by increases in one or a few incorrect sequences. Figure 2 shows that overall sequence variability, measured by the U statistic, increased in the REPEAT component but not in VARY. Both main effect of contingency, $F(1, 4) = 11.187$, $p = .029$, and of dose, $F(3, 12) = 6.782$, $p = .006$, were again significant, as well as the Contingency × Dose interaction, $F(3, 12) = 12.548$, $p = .001$. One-way ANOVAs on drug dose confirmed the significant dose effect for REPEAT, $F(3, 12) = 9.911$, $p = .001$, and lack of effect for VARY, $F(3, 12) = 0.847$.

As expected, LLRR was the most frequent sequence in REPEAT, but anticipatory errors were also common. Three or four sequences were relatively frequent in VARY and, as can be seen in Table 1, there was evidence of induction from the REPEAT to the VARY component. Shown in Table 1 are the probabilities of each subject's four most frequent sequences under the 2.25 g/kg dose and the associated control block. To conserve space, data for the other doses are not given, but they were similar. Each subject (BG, RG, B, P, and BR) is represented by two columns, the left showing sequence probabilities during intervening control sessions (C) and the right showing se-

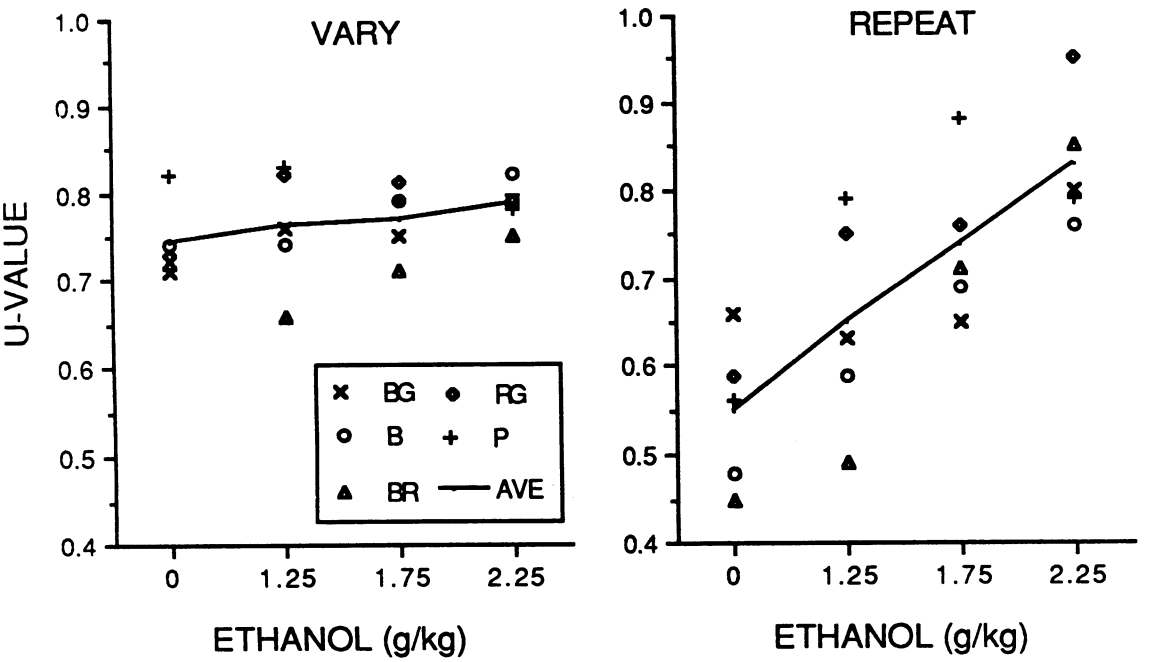

Fig. 2. Average U values, a measure of sequence uncertainty or variability, as a function of ethanol dosage for each of 5 subjects. Each data point is an average of four sessions (except if a session contained fewer than 10 trials; see Data Analysis). Performances in the VARY component are shown to the left and in REPEAT to the right. The lines connect averages of the 5 subjects.

quence probabilities when 2.25 g/kg of alcohol was administered (A). Control sessions were used for comparison because these were temporally closest to the drug sessions in question. Averages for the 5 subjects are shown in the extreme right-hand columns. The most probable REPEAT and VARY sequences, respectively, are given in the section labeled "Sequence 1," the second most probable sequences by the section labeled "Sequence 2," and so forth. In REPEAT, the two most frequent sequences during control sessions were LLRR and LRRR (i.e., the most common error was an anticipatory switch to the right lever). Ethanol caused probabilities of both sequences to decrease in all subjects and by similar amounts, the most frequent sequence decreasing from an average probability of .31 to .13 and the second most frequent sequence decreasing from .26 to .12. Because the probability of any particular sequence occurring by chance is .0625, ethanol caused the two most common sequences in REPEAT to approach chance levels.

In the VARY component, the most frequent pattern for all subjects under control conditions was LLLL. In marked contrast to REPEAT, ethanol caused no change in the average probability of its occurrence, with 3 subjects increasing and 2 decreasing. The second most frequent control sequence in VARY was LLRR for 3 subjects and LRRR for the remaining 2, both of these indicating induction from REPEAT (see discussion below). Alcohol caused probabilities of these sequences to decrease in three instances (.14 to .05, .19 to .04, and .12 to .02), increase in another (.15 to .17), and remain unchanged (.25) for the last subject. Thus, probabilities of the most frequent sequences were affected differentially by alcohol under VARY and REPEAT contingencies.

We also measured two additional indices of performance at the 2.25 g/kg dose (these data were unavailable for the lower doses). The first was average time to complete each trial, that is, the time to emit four effective responses (geometric averages of the individual times to complete trials within a session were calculated). The second index was the number of responses during IRI and timeout intervals, when the chamber was dark and responses were ineffective with respect to the REPEAT

Table 1

Probability of occurrence of four most frequent sequences (1 through 4) for each subject (BG, RG, B, P, and BR) under control (C) and 2.25 g/kg alcohol (A) conditions.

	BG		RG		B		P		BR		AVE	
Component	C	A	C	A	C	A	C	A	C	A	C	A
Sequence 1												
REPEAT	LRRR		LLRR		LLRR		LRRR		LLRR			
	.30	.18	.26	.09	.31	.16	.30	.08	.39	.15	.31	.13
VARY	LLLL		LLLL		LLLL		LLLL		LLLL			
	.20	.30	.22	.33	.20	.22	.20	.0	.25	.18	.21	.21
Sequence 2												
REPEAT	LLRR		LRRR		LRRR		LLRR		LRRR			
	.29	.14	.23	.09	.26	.20	.27	.06	.27	.09	.26	.12
VARY	LLRR		LLRR		LRRR		LRRR		LLRR			
	.14	.05	.19	.04	.15	.17	.12	.02	.25	.25	.17	.11
Sequence 3												
REPEAT	LRRL		LLLR		LRRL		LLLR		LLLL			
	.08	.05	.11	.07	.11	.07	.10	.07	.05	.08	.09	.09
VARY	LRRR		LLLR		RRRR		RRLL		LRRR			
	.13	.07	.14	.10	.13	.03	.12	.03	.20	.11	.14	.07
Sequence 4												
REPEAT	LLLR		LRRL		LLLL		RRRR		RRRR			
	.07	.07	.05	.04	.04	.06	.07	.08	.05	.09	.06	.07
VARY	RRRR		LRRR		LRLL		RRRR		RRRR			
	.10	.06	.11	.02	.12	.08	.12	.07	.14	.09	.12	.06

and VARY sequence contingencies. Note that trial time was influenced both by rate of effective responses (as effective response rate decreased, trial time increased) and by number of ineffective responses (as ineffective responses increased, trial time also increased due to the IRI and timeout reset contingencies). As will be seen, however, the two measures together indicate that alcohol caused response rates to decrease in both VARY and REPEAT components.

The top of Figure 3 shows that alcohol increased the time per trial in both REPEAT and VARY components (relative to the intervening control sessions) and that this effect was considerably larger in REPEAT. A 2 × 2 repeated measures ANOVA (Alcohol/Control Condition × VARY/REPEAT Component) revealed a significant main effect of alcohol versus control, $F(1, 4) = 8.388$, $p = .044$, and a significant interaction between condition and component, $F(1, 4) = 7.552$, $p = .052$, but no significant difference between components, $F(1, 4) = 3.60$. Individual comparisons showed that the rats took significantly longer to complete trials in alcohol sessions for both REPEAT, $F(1, 4) = 8.128$, $p = .046$, and VARY, $F(1, 4) = 8.956$, $p = .040$, components. Suggesting that this increased time per trial was due to a slowing of responding, fewer ineffective responses were emitted per trial under alcohol than control conditions, this again being found in both REPEAT and VARY (lower portion of Figure 3). A Condition × Component ANOVA showed significant condition, $F(1, 4) = 10.727$, $p = .031$, and, although absolute differences were small, component, $F(1, 4) = 12.033$, $p = .026$, effects but no significant interaction, $F(1, 4) = 1.314$). Thus, alcohol caused rates of responding to decrease during both VARY and REPEAT components.

DISCUSSION

Alcohol significantly increased the variability of responding when an LLRR sequence was required for reinforcement and thereby significantly decreased reinforcement probability. In marked contrast, alcohol had little effect when variable sequences were required for reinforcement. These results are consistent with a number of previous reports. For ex-

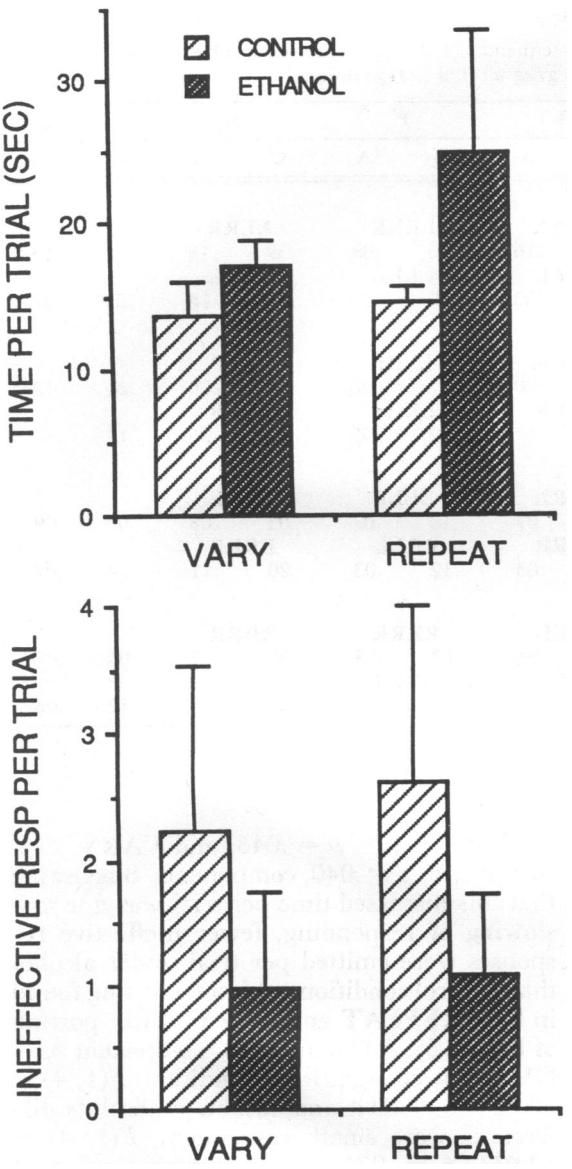

Fig. 3. The upper graph shows geometric average time per trial in VARY (left) and REPEAT (right) components during the four 2.25 g/kg alcohol (dark bars) and control (striped bars) sessions. Standard deviations are represented. The lower graph shows average numbers of ineffective responses per trial—responses during interresponse and timeout intervals—during the same sessions.

ample Bird and Holloway (1989) found that initial presentation of ethanol to rats responding under a differential reinforcement of low rate (DRL) schedule increased variability of interresponse times, especially at the higher doses. Laties and Evans (1980) found that pigeons' run-length variability under a fixed consecutive number schedule increased with ethanol dose. But the current results appear to conflict with findings from two other procedures, namely radial-arm maze and repeated acquisition of response sequences. Each of these will be discussed.

In one common version of the radial-arm maze procedure, a pellet is placed at the end of each of eight alleys that radiate as spokes on a wheel from a central platform. A food-deprived rat is given free access to the maze until all eight pellets are eaten. Pellets are not replaced once they are eaten, and therefore optimal behavior involves the rat visiting each arm only once (Olton & Samuelson, 1976). Rats make relatively few "errors," defined by repeated visits to a given arm, and, furthermore, visit arms in quasi-random fashion (i.e., they do not follow a fixed pattern of visitations). Alcohol, especially at higher doses, increases repetitions and therefore increases errors (Devenport, 1984; Devenport, Merriman, & Devenport, 1983). The conclusion reached from these results has been that alcohol is "an agent of behavioral stereotypy" (Devenport et al., 1983, p. 58), a conclusion that appears to conflict with the present results. Reinforcement contingencies under the radial-arm procedure are similar to VARY contingencies in that repetitions (of arm entries in one case and lever-press sequences in the other) are never reinforced. Therefore the different effect of alcohol—decreased variability in radial mazes versus no change under operant VARY contingencies together with increased variability under operant REPEAT contingencies—is puzzling.

A number of explanations are possible (see McElroy & Neuringer, in press). Most importantly, however, the differences may be only apparent. McElroy and Neuringer simulated radial maze studies with a computer-based random generator allocating responses among the arms of the maze. When performances of rats were compared with the simulated random generator, alcohol was seen to change the rats' behavior in the direction of the random generator. Under control conditions, rats avoid repetitions of arm entries more than would be expected by chance (e.g., Devenport, 1983, 1984; Devenport & Merriman, 1983; Devenport et al., 1983). Alcohol increases repetitions, resulting in a closer approximation to a ran-

dom generator. Thus, under both radial maze and operant REPEAT contingencies, baseline behavior deviates significantly from random: In the radial maze, baseline alternations are more frequent than would be predicted by chance; under REPEAT contingencies, baseline repetitions are more frequent than by chance. In both cases, alcohol causes performances to approach chance levels. On the other hand, when baseline behavior is already variable, as under VARY contingencies, alcohol has little or no effect on overall variability.

The second area of research involves comparisons of two types of operant schedules: under a performance schedule, a single sequence of four responses must be repeated, analogous to the present REPEAT component; under an acquisition schedule, a different sequence of four responses must be learned each session, in some ways analogous to the present VARY contingencies (Barthalmus, Leander, & McMillan, 1978). Thus, for example, under performance conditions, pigeons were required to repeat a particular sequence of responses on three keys (e.g., left, right, left, center). Under acquisition contingencies, the correct sequence was changed after each session (see also Harting & McMillan, 1976). As in the present research, performance and acquisition contingencies have also been presented under a multiple schedule (e.g., Higgins, Bickel, O'Leary, & Yingling, 1987). In both pigeons (Barthalmus et al., 1978) and people (Higgins et al., 1987), alcohol generated more errors under acquisition than performance schedules. The difference between these results (i.e., alcohol has greater effects when different sequences must be learned than when a single sequence must be repeated) and the present results (i.e., greater effects when a single sequence must be repeated than when sequences must be varied) is again puzzling.

To reconcile the findings, future research must experimentally compare performances under the three contingencies involved when (a) a single sequence is reinforced across sessions; (b) required sequences are changed after every session; (c) required sequences are changed after every trial (e.g., as under the present VARY contingencies). It is possible to speculate, however, based on the findings to date, that alcohol would debilitate performances most severely in condition (b), then (a), and have least effect in (c).

One factor that may be important in accounting for such results is task difficulty (Pandina, 1982). There are a number of reasons to suspect that the REPEAT requirement was more difficult than VARY (e.g., more sessions were required to train LLRR than to train VARY performance). In the repeated sequence experiments just described, baseline errors in acquisition components were higher than in performance components (e.g., Barthalmus et al., 1978; Higgins et al., 1987). Thus, task difficulty may influence the effects of alcohol. However, McElroy and Neuringer (in press) explicitly varied the difficulties of REPEAT and VARY contingencies. Although alcohol had greater effects on a difficult REPEAT sequence, LLRR, than on an easy one, LLLL, alcohol significantly increased variability under both. On the other hand, when the VARY contingencies were made more difficult by imposing a Lag 12 requirement, alcohol again had no significant effect on sequence variability. Thus, either task difficulty will not account for the differences between VARY and REPEAT or the VARY lag requirement does not influence difficulty (i.e., responding variably is relatively easy independently of lag).

Another important factor may be the discriminative stimuli that control performances (see e.g., Laties & Weiss, 1966). Under REPEAT, the first response in a sequence is presumably under the stimulus control of the just preceding reinforcement or timeout (i.e., the first response follows the end of the previous trial). Each additional response in the trial may be under partial control of the just-preceding response(s). Thus, memory for preceding responses is important in the generation of successful REPEAT sequences. External stimulus control may be involved in successful radial-arm maze performances as well as in repeated response sequence performances. In the maze, important controlling stimuli involve spatial cues (Olton, Collison, & Werz, 1977); that is, the rats learn not to return to a particular spatial location. Under the repeated sequence performance procedure, color cues are provided to pigeons as a discriminative stimulus for the particular response in the sequence (Barthalmus et al., 1978), or a printed number indicates the location in the sequence for human subjects (Higgins et al., 1987). In each of these cases, in which discriminative

cues are hypothesized to control performance, alcohol increased errors or changed performances in the direction of a random generator. Only under VARY contingencies does alcohol have little or no effect, possibly supporting the Page and Neuringer (1985) hypothesis that operant variability does not depend upon memory for preceding events, but depends instead upon a different generating mechanism, the "internal variability generator."

Consistent with other findings in the literature, alcohol slowed responding in both the REPEAT and VARY components (e.g., Bird & Holloway, 1989). These changes in response rate may have contributed to the differential effects on percent reinforcement under VARY and REPEAT contingencies. Neuringer[1] found that as response rates were decreased systematically through manipulations of interresponse intervals, probability of reinforcement under VARY contingencies increased. Furthermore, under a schedule analogous to the present REPEAT, the opposite function was observed (i.e., REPEAT performances were increasingly impaired as response rates decreased). In the present case as well, percentages of correct REPEAT sequences were related inversely to rates of responding. On the other hand, in the VARY component, we did not observe a significant change in percentage of reinforced sequences with response rates.

The present results are consistent with those obtained by McElroy and Neuringer (in press) and extend their findings to a multiple VARY–REPEAT schedule. In addition, interactions were seen between performances in the two components of this multiple schedule (see also Barrett & Stanley, 1980), as shown by a comparison of the most frequent sequences under the present VARY contingencies with those under analogous VARY contingencies in the study of McElroy and Neuringer. In the latter case, separate groups of animals experienced VARY and REPEAT contingencies, and therefore induction from one schedule to the other was not possible. The three most frequently emitted VARY sequences in the present experiment were LLLL, LLRR, and LRRR (Table 1). All three begin with "L," the first response required in the alternate REPEAT component. One sequence is the required REPEAT sequence, LLRR, and another a frequent anticipatory error in REPEAT, LRRR. In the study by McElroy and Neuringer, where one group of rats experienced only VARY contingencies and another group only REPEAT, the VARY subjects were most likely to emit RRRR, with RLLL, LRRR, LLLL, and RLRR also being among the three most frequent patterns for individual subjects. Despite the differences in particular "most frequent patterns" in the two experiments, the basic results were the same: The four most frequent patterns under a Lag 5 VARY contingency comprised the majority of the sequences.

Alcohol-induced variability might help to explain why some individuals drink alcohol, as indicated by the following. Habitual and repetitive behavior need not be functional, nor does it necessarily optimize reinforcement (e.g., Harriman, 1955; Maier & Seligman, 1976; Morse & Kelleher, 1977; Skinner, 1948; Young & Chaplin, 1945). To the extent that alcohol increases behavioral variability, the high probability of such nonfunctional habits may be decreased, with an increased probability of reinforcement consequent upon other behavior. When alcohol-induced variability increases reinforcing consequences, the behavior of drinking alcohol becomes an early member of a reinforced response chain. Furthermore, the alcohol drug state may then become a discriminative stimulus for this increased reinforcement (Goodwin, Powell, Bremer, Hoine, & Stern, 1969). Of course other mechanisms, including associative conditioning, physiological addiction, tolerance, and genetic differences, are important (Brady, 1988; Masur & Lodder Martins dos Santos, 1988; Staiger & White, 1988; Vuchinich & Tucker, 1988). But if reinforcement resulting from behavioral variability does, in fact, help support alcohol intake during early stages of dependency formation, the probability of establishing such dependencies may be decreased by generating behavioral variability through other means. Variability could be reinforced directly (Blough, 1966; Bryant & Church, 1974; Holman, et al., 1977; Machado, 1989; Neuringer, 1986; Page & Neuringer, 1985; Pryor et al., 1969), or otherwise increased (e.g., by slowing responding). We hypothesize that the probability of estab-

[1] Neuringer, A. (1988). *Behavioral variability: Chaotic bases of learning.* Paper presented at the meeting of the American Psychological Association, Atlanta.

lishing an alcohol dependency may be decreased if behavioral variability is increased through other means. This hypothesis may also be relevant to other variability-inducing addictive substances.

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