**EFFECTS OF ETHANOL ON MULTIPLE
FIXED-INTERVAL FIXED-RATIO SCHEDULE
PERFORMANCES: DYNAMIC INTERACTIONS AT
DIFFERENT FIXED-RATIO VALUES**

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Key pecking by three pigeons was maintained under a multiple fixed-interval fixed-ratio schedule of food presentation. The fixed-interval value remained at 3 minutes, while the fixed-ratio size was increased systematically in 30-response increments from 30 to either 120 (two pigeons) or 150 (one pigeon). At least two lower fixed-ratio values were also redetermined. The effects of ethanol (.5 to 2.5 g/kg) were assessed at each of the different schedule parameters. Both overall and running response rates under the fixed-ratio schedule decreased with increases in the size of the fixed-ratio schedule; pause duration under the fixed-ratio schedule was directly related to increases in fixed-ratio size. Overall and running rates of responding under the fixed-interval schedule changed little with increases in the size of the fixed-ratio schedule. Despite the relative invariance of fixed-interval responding across the different fixed-ratio values, the effects of ethanol on responding under the fixed-interval schedule differed depending on the size of the fixed-ratio schedule. Greater increases occurred in both overall and in lower local rates of responding under the fixed-interval schedule when the fixed-ratio value was 120 or 150. The effects of ethanol on responding under the fixed-ratio schedule also depended on the size of the fixed ratio. Increases in responding under the fixed-ratio schedule were typically greater at the higher fixed-ratio values where response rates were lower. When the effects of ethanol were redetermined at the lower fixed-ratio parameter values, rates and patterns of responding were comparable to those obtained initially. However, the dose-effect curves for responding under both fixed-ratio and fixed-interval schedules were shifted up and to the right of those determined during the ascending series. The effects of ethanol can depend on rate of responding, behavioral history, and the context in which behavior occurs.

Key words: ethanol, fixed-ratio schedule, fixed-interval schedule, multiple schedule, interactions, rate dependency, pigeons

The analysis of performances under schedules of reinforcement has yielded fundamental information not only about the control of behavior by environmental consequences, but has also contributed substantially to an understanding of the behavioral effects of drugs. Early research by Dews (1955, 1958) emphasized the importance of the schedule-controlled rate and pattern of responding engendered under nondrug conditions as principal determinants of drug effects on behavior. Research since then has amplified and extended this

emphasis (see recent reviews by Dews & DeWeese, 1977; Dews & Wenger, 1977; McKearney & Barrett, 1978).

One of the most frequently used methods of analyzing the behavioral effects of drugs has been the multiple fixed-interval (FI) fixed-ratio (FR) schedule under which quite distinctive performances are separately controlled by different stimuli (Ferster & Skinner, 1957). Multiple FI FR schedules possess certain dynamic properties wherein changes in one of the schedules or in the sequence of schedule components can affect performance maintained under the other schedule (Ferster & Skinner, 1957; Morse, 1966; Zeiler, 1977). Though such interactions are not uncommon, they have not often been the direct focus of experimentation in behavioral pharmacology.

Waller (Note 1) examined the effects of chlorpromazine on the performance of pigeons responding under a multiple FI FR schedule where the FR schedule had values of 33, 66,

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99, or 165 and the FI was either 3 min or 1 min. In this experiment performances under the FI were largely unaffected by changes in the FR value. Despite this relative invariance under the FI component, however, chlorpromazine did produce different effects on local response rates under the FI component as a function of the FR value. This finding suggested that drug effects may actually reveal or amplify certain dynamic properties of multiple schedules that are not otherwise apparent in control performances.

The present experiment was conducted using a procedure similar to that of Waller (Note 1), except that interest was focused on the effects of ethanol. Previous experiments that have examined the effects of ethanol on behavior maintained under FR or FI schedules have generally found that the effects are dependent on the schedule-controlled rate and pattern of responding. Typically, responding under FI schedules is either unaffected or decreased by doses of ethanol that either increase or do not affect responding under FR schedules (Katz & Barrett, 1978, 1979; Leander, McMillan, & Ellis, 1976). When in the present study the FR value was varied systematically while the FI value remained the same, further effects of ethanol were revealed that indicate the additional importance of the entire schedule complex and behavioral history as potent factors determining the effects of ethanol on behavior.

METHOD

Subjects

The subjects were three experimentally naive adult White Carneaux pigeons obtained from the Palmetto Pigeon Plant, Sumter, S.C. They were maintained at 80% of their free-feeding body weights. The pigeons were housed in individual cages with water and crushed oyster shells continuously available.

Apparatus

Experiments were conducted in a single-key pigeon chamber (28 by 28 by 23 cm) constructed after those described by Ferster and Skinner (1957). The response key (R. Gerbrands Co.) was centered on the front aluminum wall, 22 cm above the floor. The key could be transilluminated with either red or green 7.5-W lamps. A peck on the key that exceeded a force of 15 g (.15 N) counted as a response

and also produced the click of a relay mounted behind the front panel. Mixed grain was presented for 4 sec through an opening 15 cm below the key; during grain presentation the grain magazine was illuminated with white light and the keylights were extinguished. The experimental chamber was placed in a sound-attenuating enclosure that was equipped with an exhaust fan and a speaker through which white noise was continually presented.

Procedure

All pigeons were trained to key peck by the method of successive approximations (Ferster, 1953; Morse, 1966). During initial training, each peck produced food (fixed-ratio one or FR 1 schedule); after approximately two days of training under the FR 1 schedule the FR response requirement was increased gradually to 30 where it remained for approximately 20 sessions. The keylight color was green during this and all subsequent FR schedule components. After responding was well established under the FR 30 schedule, the second component was introduced. In the presence of a red keylight, the first response after 3 min produced food (fixed-interval or FI 3-min schedule). The FI and FR components of this multiple schedule alternated regularly. Each session consisted of 10 components of each schedule.

After approximately 30 sessions a 1-min limited hold was added to both components. If responding did not meet the schedule requirements within 1 min of the onset of the stimulus correlated with the FR schedule or after 4 min under the FI schedule, that component terminated automatically without food and the schedule alternated to the next component. The FR was reset at the beginning of each FR schedule component.

The effects of ethanol were studied first under the multiple FI 3-min FR 30-response schedule. Once dose-effect curves were completed, the FR value was increased to 60 where ethanol was again administered. This procedure was repeated at FR values of 90, 120 and 150 (P-660 only). The FR value was then decreased and performances and the effects of ethanol were redetermined at two of the lower ratio sizes. Throughout all phases the FI schedule remained at 3 min, although the duration of the FR limited hold was in-

Table 1

Sequence of schedules and number of sessions at each schedule condition.

Multiple FI 3-min FR N	P-642	P-652	P-660
FR 30, limited hold 1 min	1-85	1-101	1-93
FR 60, limited hold 2 min	86-121	102-206	94-152
FR 90, limited hold 10 min	122-167	207-309 ^a	153-192 ^a
FR 120, limited hold 10 min	168-311	310-446	193-236 ^b
FR 150, limited hold 5 min	—	—	237-332
FR 90, limited hold 10 min	312-358	—	333-369
FR 60, limited hold 5 min	—	447-495	—
FR 30, limited hold 1 min	359-397	496-536	370-408

^aLimited hold was 5 min for P-652 and 2 min for P-660.

^bLimited hold was 5 min for P-660.

creased with successive increments in the FR. It was considered essential that baseline performances at each of the FR schedule values be integrated and well maintained, not disrupted by extensive mid-ratio pauses. Consequently, at the higher FR values, increments in size of the ratio were sometimes made in steps of 5 or 10 responses and decreased if extensive pausing developed. Table 1 summarizes the sequence of exposure of all pigeons to each of the schedule conditions, the number of sessions at each schedule, and changes in schedule parameters.

Ethanol administration. Ethanol (16% V/V solution with tap water) was administered after response rates and patterns of responding showed no systematic trend over a 5-day period. The drug was administered 30 min prior to a session by inserting a 15.2 cm curved stainless steel animal feeding tube (Popper and Sons) to the level of the opening of the proventriculus. Drug administrations were typically conducted on Tuesdays and Fridays if performances on Monday and Thursday were comparable to those prior to the beginning of the drug series. Equicaloric doses of dextrose solutions or equivalent volumes of water were also occasionally given on days when ethanol would have been administered. Each dose was typically given at least twice in a generally non-systematic sequence; two high doses (1.5 to 2.5 g/kg) were never given consecutively.

Data analysis. Responses were cumulated across the session in five successive 36-sec intervals of the FI schedule to obtain an average measure of local response rates within the FI. Time to the first response in each schedule component (pause time) and response rates from the first response to food presentation

(running response rates) were also cumulated for each component across the entire session.

RESULTS

Behavioral data. Figure 1 shows representative cumulative response records for one pigeon (P-660) at each FR value over the entire course of the experiment. The effects shown in this and subsequent figures for P-660, unless otherwise noted, were also characteristic of the other two pigeons. At the FR 30 value, responding under the FI schedule was initiated after an initial pause and was typically positively accelerated during the intermediate portion of the interval; after this transition, a high steady rate of responding was maintained until food was presented. Under the FR 30 schedule, high steady rates of responding occurred that followed a very brief initial pause. The duration of the pause in the FR schedule component increased noticeably when the FR value was increased to 60; responding under the FI schedule did not change markedly at this FR parameter value.

Under the multiple 3-min FI 90-response FR schedule, FR pause duration increased still further. Rates and patterns under the FI also were affected little by the increase in FR size to 90. When the FR was set at 120, pause duration did not increase substantially for this pigeon, although it did for the other two subjects (Figure 2). At the 150 response FR value, pause duration increased markedly; responding in some of the FR components towards the end of the session showed less of the abrupt transition from no responding to a high steady uninterrupted rate. Instead, responding occurred occasionally in short bursts after the pause was terminated and, after a sequence of a few responses and very brief pauses, was maintained at a high consistent rate.

At the FR 120 value, patterns of responding under the FI were generally similar to those maintained at the lower FR parameter values. Response rates increased slightly under the FI when the FR 150 schedule was in effect during the alternate component and patterns under the FI did not show the pronounced positive acceleration seen at lower FR values. Except for a decrease in overall rates under the FR 30 schedule, redetermination of performances under the FR 90 and FR 30 schedule values resulted in performances generally comparable

Fig. 1. Cumulative response records of performance under the multiple FI 3-min FR N schedule where the FR value was increased systematically from 30 to 150 (P-660). X-axes: time; Y-axes: cumulative responses. The FR schedule component is indicated by the deflection of the lower event pen beneath each record. The FI schedule was in effect when the pen was not offset. Diagonal marks on the record indicate food deliveries. The pen was reset after approximately 1,100 responses were cumulated. Note that as the FR value was increased, pause duration during that schedule component was also increased. FI rates and patterns changed little, except at the FR 150 value.

to those obtained during the ascending series. The redetermined performance at FR 30 is shown in Figure 1.

Quantitative analyses of performances of all pigeons under the different schedules are shown in Figure 2. The top panel of this figure shows changes in overall response rates under the FR and FI schedules as a function of FR size. As noted above for P-660, overall rates of responding under the FI were generally not affected across the range of FR values from 30 to 120; slight increases did occur for P-660 at the 150 FR value. Overall response rates under the FR schedule also decreased systematically

for the other two pigeons with increases in FR size. Except for P-652 at FR 120, overall rates of responding under the FR schedule were uniformly above those maintained by the FI at all parameter values. When FR values were redetermined all points fell quite close to those obtained during the ascending portion of the study.

The middle panel of Figure 2 depicts changes in run rates across the FR values. For the most part these effects parallel those shown with overall rates in the top panel of the figure. Run rates under the FR schedule were inversely related to FR size, whereas FI run

Fig. 2. Effects of FR value on overall rate of responding (top), response rates from the termination of the pause to food delivery (run rates, middle), and pause duration (bottom). Circles denote responding under the FI schedule, triangles under the FR schedule. Arrows denote the sequence of exposure to the different experimental conditions. Data are taken from control values (Thursdays or control days) at each FR value and usually represent at least five observations. Vertical lines represent ranges of observations.

rates changed little with increases in the value of the FR. Slight increases in FI run rates at the higher FR parameter values occurred with P-660 and P-652.

The bottom panel of Figure 2 shows that pause duration under the FR schedule increased markedly as the FR value was increased. Pause duration under the FI schedule remained fairly uniform across the ascending series of FR values, although for all pigeons, pause duration was generally longer for re-

determined points. The lower two panels of Figure 2 indicate that changes in overall response rates under the FR schedule shown in the top section were a function both of increases in pause duration and decreases in run rates.

Effects of ethanol under the FR schedule. Figure 3 shows the effects of ethanol on overall rates of responding of all pigeons under the FR schedule as the FR size was increased to FR 120 (150 for P-660) and then decreased to FR 30. When response rates were highest, at FR 30, most doses of ethanol either had no effect on or decreased responding; there was a slight increase in response rate with P-642 at the .5 g/kg dose. As the FR value was increased to 60, responding was either decreased less (P-660) or was increased (P-642 and P-652) except at the higher doses. At FR 90 low to intermediate doses of ethanol increased response rates with P-660 and P-652, but not with P-642. Substantial increases in responding occurred at the highest FR value with P-642 (FR 120) and P-660 (FR 150). Responding was not increased at the FR 120 value with P-652 or P-660.

Except for P-652 at FR 30, when the effects of ethanol were redetermined at the lower FR values the dose-effect curves were typically shifted at least one dose to the right and were above those initially determined. This indicates that when the effects were redetermined at lower FR values after exposure to the larger values, higher doses were necessary to produce comparable effects; further, doses that previously had no effect on or decreased responding now produced increases.

Increases in overall rates obtained with ethanol were not due exclusively to a shortening of the pause preceding the initiation of responding. Figure 4 indicates that increases also occurred in running response rates, timed from the occurrence of the first response in the ratio to the delivery of food. Generally, these increases were less than those found with overall rates of responding (Figure 3). As with the effects of ethanol on overall response rates, redetermined dose-effect curves for running rates were shifted up and to the right of those determined initially. This shift also occurred with P-652, the pigeon that did not show a shifted dose-effect curve with overall rates (Figure 3). This finding suggests that changes

Fig. 3. Dose-effect curves of the effects of ethanol on overall rates of responding under the FR schedule when the FR size was increased from 30 to 120 responses (150 for P-660). Unfilled symbols represent redetermined values. Unconnected points at the extreme left denote mean control values ± 1 S.E. Vertical lines above ethanol doses represent the range of measures.

in pause duration account for the difference in effects on overall rates for this pigeon at the redetermined FR 30 value (see Figure 5).

Figure 5 shows the effects of ethanol on pause duration under the FR schedule at each FR parameter. Across most values of the FR schedule, low to moderate ethanol doses generally had little effect on or slightly increased pause duration. At the higher FR values for P-642 (FR 120) and P-660 (FR 150), pause duration was decreased by low doses of ethanol. These were the same doses and FR values that showed the greatest increase in overall response rates with these pigeons (Figure 3). Taken together with the data shown in Figure 4 on running response rates, the data on pause duration indicate that the increases in overall rates at the highest FR values were due primarily, although not exclusively, to a decrease in pause duration. With the exception of P-652 at FR 30, the pause data in Figure 5 also show the same shift to the right in the dose-effect curves as was obtained with overall and running response rates. Redetermined points for pause duration were below those determined during the ascending series, indi-

cating that, compared to the initial determination, the same dose had less effect on or decreased pause duration.

Effects of ethanol under the FI schedule. The effects of ethanol on overall response rates under the FI schedule at different FR values are shown in Figure 6. At the lower FR values (FR 30 and FR 60), ethanol generally had little effect on or decreased responding, although increases did occur with P-652 at certain doses. As the FR value was increased to 90 and then 120 or 150 (P-660), sizeable increases in responding occurred for all pigeons under the FI schedule, even though overall rates changed little (Figure 2).

Redetermined dose-effect curves for responding under the FI schedule were typically shifted up and to the right of those determined during the ascending series of FR values. Substantial increases in response rates occurred under the FI at FR parameter values and FI response rates that did not previously yield increases. At the FR 30 value, for example, ethanol produced marked increases in response rates under the FI schedule that were above those obtained initially.

Fig. 4. Effects of ethanol on FR response rates occurring after the first response in the FR and continuing until food delivery (running response rates). Unconnected points at the extreme left of each figure represent mean control response rates ± 1 S.E. Vertical lines above doses represent ranges. Unfilled symbols denote redetermined values.

Increases in running response rates also occurred at doses that produced increases in overall rates, although these were usually smaller in magnitude (Figure 7). Again, redetermined dose-effect curves generally were shifted to the right and upwards of those determined initially.

At the lower FR values, low doses of ethanol had little effect on pause duration, and higher doses increased it (Figure 8). Ethanol decreased pause duration slightly when the FR was set at the higher parameter values indicating, as with the FR, that increases with ethanol in overall FI rates reflect both increases in running rates and decreases in pause duration. Redetermined functions for pause duration were shifted only slightly to the right and occasionally down from those determined during the initial ascending phase of the study. These findings are similar to those for the other measures of responding under the FR and FI schedules.

Figure 9 shows cumulative records depicting the effects of ethanol on performance of P-660. The 1.5 g/kg dose was selected to characterize

ethanol's effects at each parameter value and for the redetermined dose-effect curves. Under the initial exposure to the FR 30 schedule, this dose of ethanol decreased response rates under both the FR and FI schedules (Figures 3 and 6). Positively accelerated patterns were still maintained under the FI and integrated performances were maintained under the FR, even though overall rates were decreased. When the effects of ethanol were redetermined under the FR 30 schedule after exposure to higher FR values, responding under both FR and FI schedules was increased at this dose (see also Figures 3 and 6).

At FR 60 the 1.5 g/kg dose of ethanol decreased FI responding to a greater extent than responding under the FR schedule (Figures 3 and 6). Responding during certain intervals (for example the second, fourth, and seventh) was nearly eliminated, but during the alternate FR component responding was largely unaffected.

Figure 9 also shows the striking differences between the initial and redetermined effects of 1.5 g/kg ethanol at FR 90. Responding was

Fig. 5. Effects of ethanol on FR pause duration under different FR parameter values. Y-axes are logarithmic. Points at extreme left denote mean control values ± 1 S.E. Unfilled symbols with broken lines represent redetermined values; vertical lines above doses reflect ranges.

markedly disrupted at this dose during the ascending phase of the study; response rates were very low during the initial portion of the session and for the first nine components the limited hold elapsed without food delivery. Responding returned first in the FR component and was comparable to that occurring under control conditions for the remainder of the session (Figure 1). When the dose-effect curve was redetermined at FR 90 after exposure to higher FR values, the 1.5 g/kg dose had little effect on FI responding and increased responding under the FR schedule (see also Figures 3 and 6).

When the FR size equalled 120, responding under the FI schedule for P-660 was increased slightly, whereas under the FR schedule, slight decreases occurred. During certain FR schedule components, responding was positively accelerated. At the FR 150 value responding under both components was increased at the 1.5 g/kg dose. The initial pause duration in both components was decreased considerably (see

Figures 1, 5, and 8), but patterns maintained by the two schedule components were still quite distinctive.

Rate-dependent effects. Figure 10 shows the effects of ethanol on average local response rates within successive 36-sec segments of the FI. As a general rule at doses above .5 g/kg, relatively lower local rates of responding were increased, whereas higher rates were unaffected or decreased. The magnitude of these effects, however, differed depending on the parameter value of the FR in the alternate component. For example, the 1.0 to 2.0 g/kg doses increased lower local FI rates of responding to a greater extent when the FR size was 120 to 150. The 1.5 and 2.0 g/kg doses also affected local response rates differently depending on whether the rates were taken from the initial determination (filled symbols) or represented redetermined dose-effect curves (unfilled symbols). At the 1.5 and 2.0 g/kg doses, points from the second determination were typically above those found initially, indicating local FI re-

Fig. 6. Effects of ethanol on overall response rates under the FI schedule at different FR values. Symbols to extreme left represent mean control values ± 1 S.E. Unfilled symbols and broken lines represent redetermined values. Vertical lines above ethanol doses represent the ranges.

sponse rates were increased more or decreased less during the redetermination at those FR values.

A similar analysis was performed on the wide range of both overall and running response rates obtained over the different FR parameter values (Figure 11). An analysis of run rates was included to compare effects of ethanol on the relatively homogeneous response rates that occur under FR schedules when pause duration is excluded, thereby circumventing a potential problem in averaging different rates under FI schedules (Branch & Gollub, 1974). As with the local rates under the FI schedule, there was a general tendency for the lowest FR rates, obtained at the higher FR values, to be increased at doses that decreased the higher FR rates. These effects on FR rates occurred regardless of whether the data included pause duration (circles) or were analyzed exclusive of pause (triangles).

DISCUSSION

In this experiment performances under the FR component of a multiple FR FI schedule

changed systematically with changes in the FR value, whereas performance during the alternate FI schedule remained relatively invariant. The effects of ethanol on responding under *both* schedules, however, depended on the size of the FR. Ethanol produced greater increases in the lower FR rates of responding maintained at the higher FR values. These effects under the FR schedule are consistent with what has been found previously with drugs that produce rate-dependent effects (see Dews & Wenger, 1977, and Sanger & Blackman, 1976), i.e., an inverse relationship between response rate and the drug effect.

The different effects of ethanol on FI performance at the different FR values cannot be accounted for in this manner, however, since response rates in this component changed little across all FR parameter values. Ethanol increased both overall and lower local response rates to a much greater extent at the higher FR values. Waller (Note 1) also found differences in the effects of chlorpromazine on local response rates within an FI schedule with changes in the FR parameter value, al-

Fig. 7. Effects of ethanol on response rates under the FI, measured from the first response in the FI to the delivery of food (running response rate), as a function of the FR parameter. Points to the extreme left denote mean control measures ± 1 S.E. Vertical lines at each dose represent ranges. Unfilled symbols and dashed lines reflect redetermined values.

though overall rates were not differently affected. These changes reflect the importance of the multiple schedule as a dynamic unitary complex (Waller, Note 1) and further emphasize the role of the total environmental context in which behavior occurs as a significant feature determining the behavioral effects of drugs (McKearney & Barrett, 1975, 1978). It is important to note that the dynamic nature of these contextual features was not evident in control performances under the FI schedule and that ethanol revealed influences that were not otherwise apparent in ongoing behavior.

The importance of both response rate and the dynamic properties of the schedule was also indicated by the rate-dependent analyses of drug effects on different response rates under the FR schedules and the changes in local rates under the FI. As shown previously, the effects of ethanol on average local rates under the FI were dependent on the within-interval response rate; lower local rates were increased at doses that did not affect or decreased higher local rates (Leander, McMillan, & Ellis, 1976;

Katz & Barrett, 1978, 1979). This result was also found in the present study, with the additional finding that the slope of the regression lines under the FI schedule depended on the FR value in the alternate component.

The use of average local response rates has been criticized because the average rate derived from cumulating responses into segments of the interval potentially results in the combination of different rates; under such conditions the average figure may not accurately reflect the measures on which it is based (Branch & Gollub, 1974). The present study yielded different FR rates of responding at the different FR values. These rates are more homogeneous both within and across each FR than is typically true under FI schedules. Consequently, it seemed appropriate to analyze FR performances for rate-dependent effects. The data shown in Figure 11 for run rates under the FR seem to demonstrate quite clearly that the effects of ethanol on performances under the FR schedule are dependent on the rate of responding. Further analyses of this type would

Fig. 8. Effects of ethanol on pause duration under the FI schedule as a function of the FR parameter value. Y-axes are logarithmic. Points at the left represent mean control measures ± 1 S.E. Unfilled symbols denote redetermined dose-effect curves. Vertical lines above ethanol doses represent range of observations.

appear to obviate many of the criticisms and the concerns related to the generality of rate-dependent analyses derived from FI schedules.

The behavioral effects of drugs can be the result of multiple interactive factors. In addition to the importance of response rate and the environmental context, drug effects are also determined by the behavioral history of the organism. It has been shown, for example, that the effects of *d*-amphetamine on punished responding can be completely reversed by prior nondrug experience (Barrett, 1977; also see review by McKearney, 1979, and articles by Poling & Appel, 1978; Urbain, Poling, Milam, & Thompson, 1978). In addition, the actual consequences of responding in the presence of a drug may modify the subsequent effects of that drug on behavior (Smith &

McKearney, 1977). Behavioral experience would also seem to account for the finding in the present study that the effects of ethanol were qualitatively different during the ascending and descending series. Ethanol consistently increased both FR and FI responding at the higher valued FR schedules, an effect that did not initially occur when the FR value was low. Subsequently, upon re-exposure to the lower FR values, increases in responding occurred with ethanol under both FR and FI schedules that were not initially obtained.

The finding that higher doses were necessary to produce decreases in responding resembles the development of tolerance to ethanol. However, several factors suggest that drug tolerance cannot account for these effects. First, the determination of dose-effect curves at each FR parameter value was often separated by over

Fig. 9. Cumulative response records of the effects of 1.5 g/kg ethanol on responding under the multiple FR FI schedule (P-660). The FR value was changed systematically from 30 to 150 and the effects of ethanol were determined at each parameter. Dose-effect curves were redetermined at the FR 30 and FR 90 values. X-axes: time, Y-axes: cumulative responses. Diagonal deflections of the response pen denote food deliveries or component alternation without food (at the FR 90 value, 1.5 g/kg decreased responding such that the first 9 components alternated without food presentation). The line beneath each record was offset during the FR schedule and the pen was reset after approximately 1,100 responses were made. Note that ethanol's effects were quite different when redetermined at the FR 30 and FR 90 schedule values.

a month, during which time behavior was stabilized. Though chronic (daily) drug administration is not essential for tolerance to occur, it is significant that shifts in the dose-effect curves did not occur during the ascending series. Although pharmacological accounts of tolerance do not appear applicable to the present findings (see e.g., LeBlanc, Kalant, Gibbins, & Berman, 1969), there are a number of studies indicating that tolerance-like phenomena can emerge by environmental or nonpharmacological manipulations (e.g., LeBlanc & Cappell, 1977; Schuster, Dockens, & Woods, 1966; Siegel, 1975; see review by Corfield-Sumner & Stolerman, 1978). Both the shifts to the right in the dose-effect curve and the increased effects obtained with ethanol upon re-exposure to the lower FR values would appear to be more directly attributable to residual but enduring effects produced by

the behavioral experience and drug effects under the higher-valued FR schedules.

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Fig. 10. Effects of ethanol on local response rates during successive 36-sec segments under the FI schedule at the different FR parameter values. Both X- and Y-axes are logarithmic. X-axes: average control response rate under nondrug conditions; Y-axes: percent changes in rates of responding as a function of control rate. Lines were determined by the method of least squares. Unfilled symbols and dashed lines represent redetermined dose-effect curves. Note that the magnitude of change in response rate depended on the parameter value of the FR schedule in the alternate component. The effects were also dependent on whether the dose-effect curves at a given parameter value were taken from the ascending or descending FR series. Numbers to the right aid in delineating the particular lines.

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Fig. 11. Effects of ethanol on overall (circles, solid lines) and running rates (triangles, dashed lines) of responding under the FR schedule at different parameter values. Lines were determined by the method of least squares and are based only on the ascending FR series; the redetermined values, shown by the unfilled symbols, were not included in the regression analysis. Both axes are logarithmic.

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