SIMILARITIES IN THE RATE-ALTERING EFFECTS OF WHITE NOISE AND COCAINE

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The effects of white noise and cocaine on squirrel monkeys' fixed-interval responding were compared to determine whether the presentation of an exteroceptive stimulus could produce rate-altering effects of the type typically observed following drug administration. To investigate the relationship between control response rate and response rate in the presence of drug or noise, the monkeys were trained under a fixed-interval 300-s stimulus-shock termination schedule in order to generate a wide range of local response rates. A light illuminated the experimental chamber during the interval and, after 300 s elapsed, a lever press during a 3-s period terminated the light and precluded the occurrence of a harmless electrical stimulus that otherwise was delivered at the end of the 3-s period. Each interval was followed by a 30-s timeout during which the chamber was darkened and responses had no consequences. Following intramuscular administration of cocaine, different rates of responding characteristic of control performance converged toward a common rate and, at an appropriately high dose, response rate during the fixed interval became more uniform. When white noise was presented continuously during a given session, different response rates also converged toward a common rate and, at an appropriate intensity, response rate became more uniform. Interactions were obtained when cocaine and white noise were presented together, indicating the possibility of a common behavioral mechanism of action. The results suggest that rate-altering drug effects may be, in part, a result of the ability of drugs to produce nonspecific stimulus effects similar to those observed for exteroceptive stimuli.

Key words: fixed interval, stimulus-shock termination, cocaine, white noise, rate constancy, lever press, squirrel monkey

The study of response rates under schedules of reinforcement has been valuable in understanding a wide variety of behavioral phenomena including the behavioral effects of pharmacological agents. In this regard, an analysis of behavior maintained by fixed-interval (FI) schedules has been especially useful for studying the relationship between control rates of responding and rates of responding following drug administration, because a single FI schedule can generate a wide range of local response rates. Subjects responding under such a schedule typically show little or no responding early in the interval and increasing rates as the interval elapses. Despite differences

among species, drugs, and doses in whether a given rate is increased or decreased, a typical change in pattern of responding occurs that is common to a variety of behaviorally active drugs. In many cases, this pattern can be described most accurately as a convergence of predrug (control) rates toward a uniform rate. To describe this effect, Gonzalez and Byrd (1977) proposed the concept of rate constancy as an appropriate characterization of changes in behavior due to drug administration. According to the rate-constancy concept, drugs can reduce variability in the occurrence of behavior and, as drug dose increases, responding approaches a more uniform or constant rate. In addition to encompassing a wide range of rate-related drug effects, rate constancy provides a unitary description of changes in performance due to drug administration (Byrd, 1981).

Rate-related drug effects can be produced by a variety of drugs with widely divergent pharmacologies. The extent to which similar phenomena are characteristic of exteroceptive stimuli has been studied little and is poorly

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understood. McKim (1981) proposed that a common factor among drugs that produce rate-related effects is their ability to function as novel or extraneous stimuli. If one assumes that stimulus properties of drugs are similar to properties of conventional environmental stimuli, then nondrug stimuli may modulate behavior in a manner similar to that engendered by drugs. Extensive work on state-dependent learning and drug discrimination has demonstrated that a drug state can function as a discriminative stimulus and that humans and animals can be trained to behave differentially in the presence of drugs (Overton, 1971). Because drug states can act as stimuli, it is possible that changes produced by drugs are not related solely to the specific actions of drugs, and rate-related changes in particular may be nonspecific.

McKim (1973) drew attention to the similarity between "extra stimuli" and rate-related drug effects when he attempted to compare directly the effects of scopolamine and white noise on FI performance of rats. The changes produced by white noise and the drug were very similar when plotted in the typical manner, that is, control rate (R_c) on the x axis and the ratio of drug rate to control rate (R_d/R_c) on the y axis. Although the slopes were slightly different, both manipulations produced changes that were interpreted as rate related. Whether stimulus change, rather than the stimulus itself, produced the effects was not clear, however. A subsequent study by Ksir (1976) helped to clarify the phenomenon. He argued that if stimulus change were the causative factor, then removal of an habituated, chronically administered drug should result in rate-related effects similar to those produced by its introduction. To test this assumption, Ksir conducted an experiment in which rats trained under an FI schedule were injected chronically with *d*-amphetamine prior to each session. Subsequently, when saline was substituted for *d*-amphetamine on a given day, 3 of the 6 rats showed rate-related changes in FI responding that were similar to changes produced by the initial injection of *d*-amphetamine, supporting the notion that stimulus change was a causative factor. In a related experiment, Cole and Gay (1976) trained groups of rats on an alternating continuous-reinforcement (CRF)-extinction (EXT) schedule. One group received injections of

d-amphetamine prior to training sessions, and the second group received injections of saline. Subsequently, the conditions for the groups were reversed, and the drug group received saline and the saline group received *d*-amphetamine. The change in conditions did not produce a change in overall response output, but disruptions were noted in the performance of both groups in the form of an increase in EXT responding and a decrease in CRF responding, that is, a rate-related change. Although evidence in support of McKim's (1973) proposal that drugs may have effects attributable to being novel stimuli has been derived from a limited number of studies, the results suggest that his conceptualization may have value for investigating rate-related drug effects.

The present experiment was undertaken to study the effects of white noise on FI performance and to determine whether the presentation of a salient exteroceptive stimulus could produce rate-related effects of the type typically observed following drug administration. The experiment characterized the range of effects caused by white noise, compared the results with those obtained following cocaine administration, and assessed whether the effects of white-noise presentation and cocaine administration could be characterized appropriately as production of rate constancy. In addition, white noise and cocaine were presented in combination to investigate the interaction between drug and nondrug stimuli.

METHOD

Subjects

Three adult male squirrel monkeys (*Saimiri sciureus*), S-60, S-76, and S-78, were housed individually and maintained at free-feeding body weights. All subjects had been trained previously under a random-interval, stimulus-shock-termination schedule, but none had been used in an experiment for over 6 months prior to the present experiment.

Apparatus

Daily experimental sessions were conducted within a ventilated, sound-attenuating chamber with each monkey seated in a Plexiglas chair similar to that described by Hake and Azrin (1963) with modifications (Byrd,

1979). A response lever (Coulbourn Instruments, No. E21-03) mounted on a wall facing the monkey registered a response and operated a feedback relay when depressed with a force greater than 0.20 N. Illumination was provided by three pairs of 7-W ac colored lights (red, white, and blue) mounted on the front wall of the chair just above eye level. The subject's tail was held motionless in a small stock, and two brass electrodes rested on a shaved portion near the end. A 650-V ac source was used to deliver a 6-mA electric shock of 200-ms duration, and electrode paste (EKG Sol) minimized changes in resistance between the tail and the electrodes. A TRS-80® Model I microcomputer controlled experimental events on-line and recorded data as described previously (Mapou, Borowiec, Richards, & Byrd, 1984). Sessions were conducted 5 days per week, and the duration of each session was 2 hr during initial training and 1 hr during the experimental procedures. A total of 126 two-hour training sessions and 79 one-hour training sessions were conducted prior to the experimental procedures.

Procedure

Subjects were trained under an FI 300-s stimulus-shock-termination schedule with a 3-s limited hold. A red light illuminated the experimental chamber during the interval and, after 300 s elapsed, the animal had 3 s to press the lever and preclude the occurrence of a harmless electrical shock. If the subject responded during the 3-s period, the red light was extinguished, a white light was illuminated briefly (2 s), and a 30-s timeout period followed during which the chamber was darkened and responses had no consequences. In the absence of a response during the 3-s period, a shock was delivered followed by a 30-s timeout. Response rates and interresponse times (IRTs) were recorded separately for each interval.

Drug Administration and White Noise Presentation

In order to compare the behavioral effects of a drug with the behavioral effects of a nondrug stimulus, subjects were studied in a chamber devoid of white noise as a masking stimulus. On selected days, typically Tuesday and Friday, a given intensity of white noise

was presented continuously for an entire session. Intensities of 76, 78, 80, 90, and 100 dB SPL were studied twice for each monkey. An intensity of 76 dB SPL was minimally above the background or ambient noise level in the closed chamber. At an intensity of 100 dB, auditory stimulation was intense but below pain threshold (Beecher, 1974; Green, 1975). Sound intensities were presented in an ascending series followed by a descending series in order to detect possible changes in the effect of white noise due to repeated presentation. At least 3 days intervened between successive presentations of white noise. The source of the auditory stimulus was a 12-V dc white noise generator (Med Associates, No. 81-02), with variable-intensity control, connected to a 4-in. round speaker mounted on the rear wall of the chamber above the subject's head. Prior to each session, a Radio Shack Realistic sound-level meter (No. 2120938; five ranges: 60 to 116 dB) was used to measure and calibrate the intensity level at the approximate position of the subject's head inside the closed test chamber.

After all intensities of white noise were studied twice for each monkey, doses of 0.03, 0.1, 0.3, 0.56, and 1.0 mg/kg cocaine were administered twice to each monkey to permit a within-subject comparison of drug and nondrug stimuli. Cocaine hydrochloride (National Institute on Drug Abuse, Rockville, MD) was dissolved in sterile, distilled water for injection, and doses were determined in terms of the salt. Sodium chloride solution (0.9%) was used for control injections. All doses were injected intramuscularly in the thigh, in a volume of 0.4 to 0.6 mL. Drug doses were administered in a mixed sequence with at least 3 days intervening between successive administrations of the drug, and control injections were administered once per week. The behavioral test session began within 5 min after drug administration.

After all doses of cocaine were studied, white noise and cocaine were presented in combination to investigate the interaction of the drug and nondrug stimuli. An intensity of 80 dB white noise was presented in combination with 0.56 mg/kg and 0.03 mg/kg cocaine, and a dose of 0.56 mg/kg cocaine was administered in combination with 76 dB and 80 dB white noise. Each combination was studied twice in each subject.

Fig. 1. Effect of white-noise intensity on cumulative records of responding under an FI 300-s stimulus-shock termination schedule in one squirrel monkey (S-76). Deflection of the pen on the horizontal time axis indicates start of an interval. The response pen reset after 550 responses and during timeout periods scheduled between intervals. The cumulative recorder did not operate during timeout periods.

RESULTS

Effects of White Noise

Control performance during the FI 300-s schedule was characterized by little or no responding early in the interval and by higher response rates as the interval elapsed (Figure 1). Overall mean rates during control (no noise) sessions for Subjects S-60, S-76, and S-78 were 0.22, 0.77, and 0.56 responses per

second, respectively. During white-noise presentation, the response rate was increased, the pause at the beginning of the interval was shortened, and the pattern of positively accelerated responding engendered by the FI schedule became less curvilinear. The rate-increasing effect was more pronounced as the intensity of the noise stimulus was increased from 76 dB to 80 dB, and responding was most nearly uniform during each interval at 80 dB for Subjects S-60 and S-76 and at 90 dB for Subject S-78.

A plot of overall mean response rate versus intensity, in Figure 2, describes the range of effects due to white-noise presentation. For a given intensity, the average response rate during each interval was calculated and then averaged for successive intervals 3 through 10. The first two intervals of a session were omitted from the data analysis because mean response rate was frequently greater and the duration of the initial pause was shorter than that obtained for the remaining intervals (warm-up effects). The overall mean response rate per session was expressed as a percentage of control rate and was plotted on the y axis, and noise intensity was plotted on the x axis. The lowest intensity of white noise (76 dB) had a moderate effect on mean response rate, and the intermediate intensities (78 dB and 80 dB) increased rate for all subjects. The maximum rate increase occurred at an intensity of 80 dB, and higher intensities (90 dB and 100 dB) had smaller rate-enhancing effects for all subjects. Response rate remained above control level at all intensities for Subjects S-76 and S-78, and only the highest intensity (100 dB) decreased rate below control level for Subject S-60. A comparison of intensity-effect curves for the ascending and descending series of white-noise presentation did not reveal any orderly change in sensitivity to the effect of white noise due to repeated presentation.

In order to quantify further the changes in performance resulting from white-noise presentation, interresponse time (IRT) distributions were plotted and analyzed. The time between successive responses was recorded in sequence for each experimental session, and the IRTs were grouped into 41 bins according to duration. Due to the wide range of response rates for the 3 subjects, different bin widths were selected to provide comparable spreads of the IRT distributions. The 41st bin in-

Fig. 2. Effect of white-noise intensity on mean response rate for a group of 3 monkeys (top left) and for individual subjects. Effect of white noise is expressed as percentage of the mean response rate obtained when no noise was presented (100% = control). Bars indicate $\pm$ one standard deviation.

cluded all IRTs that exceeded the upper limit of the 40th bin. The high relative frequency of IRTs exceeding the upper limit of the distributions indicated frequent pauses of long duration during control sessions (Figure 3, top row of graphs). Following white-noise presentations of 80 dB (Subjects S-60 and S-76) or 90 dB (Subject S-78), there were shifts toward briefer and more uniform IRTs and the relative frequency of IRTs exceeding the upper limit of the distribution was markedly reduced (Figure 3, bottom row of graphs). Each of the distributions in Figure 3 was derived from a single representative session and is not the result of averaging across sessions.

Response rate in each of ten 30-s segments of each FI was also calculated and then averaged for FI components 3 through 10. Response rate for each segment with noise present was plotted against control rate on logarithmic axes, and a linear regression line was determined using a least squares estimate. A diagonal line with a slope equal to +1.0 indicated no change from control sessions; a

horizontal line with a slope equal to zero would indicate that response rate during noise was constant. A regression line was plotted for each intensity to determine whether the effects of white noise were consistent with the concept of rate constancy. The result was an orderly decrease in the slope of the regression line for all subjects as noise intensity increased from 76 dB to 80 dB (Table 1). Individual regression lines for each subject revealed that the decrease in slope was due to increases in the low response rates during the early segments of the interval (Figure 4). The higher response rates during the later segments of the interval were either unchanged (S-76 and S-78) or slightly increased (S-60).

Response rate during noise versus control rate was compared for individual subjects, and the mean of the data points comprising the regression line with a slope closest to zero was defined as the most constant rate for that subject under that set of conditions. An intensity of 80 dB produced a minimum slope (0.27) for Subject S-60, and an intensity of 90 dB

Fig. 3. Effect of white-noise intensity on interresponse time (IRT) distributions for individual subjects. Each distribution is derived from fixed intervals 3 to 10 of a single session. N = total number of responses emitted for each distribution. Relative probabilities greater than 0.2 are indicated numerically above a broken bar.

produced a slope (0.02) closest to zero for Subject S-78 (Table 1). There was little difference in the slope at intensities of 80, 90, and 100 dB for Subject S-76. Therefore, the regression line determined for an intensity of 80 dB (slope = 0.14) was considered the point at which a most constant rate was produced because the rate-enhancing effect of white

noise diminished at higher intensities. Using these criteria, the most constant rate for Subjects S-60, S-76, and S-78 was 0.45, 1.65, and 1.07 responses per second, respectively.

Effects of Cocaine

During the cocaine versus saline experimentation, overall mean response rates during control (saline) sessions were 0.27, 0.89, and 0.24 response per second for Subjects S-60, S-76, and S-78, respectively. Thus, control rates were similar during the noise and cocaine experiments for Subjects S-60 and S-76. For S-78, however, a decrease in response rate during the early segments of the FI resulted in lower control rates during the cocaine experiment compared to control rates obtained during the noise experiment. Following cocaine administration (0.03–0.56 mg/kg), response rate increased, the pause at the beginning of the interval shortened, and the pattern of positively accelerated responding engendered by the FI schedule became less curvilinear (Figure 5). To characterize the effects of cocaine, the average response rate during each FI completion was calculated for individual

Table 1

Effect of white-noise intensity on fixed-interval performance in 3 squirrel monkeys. *Rate* corresponds to overall mean rate of responding (responses per second) during a session. *Slope* was derived from a linear regression analysis of local response rates during 30-s segments of the FI 300-s schedule when rate during noise presentation was plotted relative to rate without noise.

Sound intensity (dB)	Squirrel monkey					
	S-60		S-76		S-78	
	Rate	Slope	Rate	Slope	Rate	Slope
76	.25	1.29	1.04	.38	.66	.48
78	.25	.79	1.33	.19	1.09	.14
80	.45	.27	1.65	.14	1.14	.13
90	.29	.39	1.59	.12	1.07	.02
100	.18	.62	1.38	.09	1.01	.12

Fig. 4. Effect of white-noise intensity (dB) on mean response rate during individual 30-s segments of an FI 300-s schedule for individual subjects. Response rate during a given 30-s segment when white noise was presented is plotted as a function of response rate for that segment during control sessions. Response rate for each segment is the mean for FI components 3 to 10. Regression lines were fitted by the method of least squares. The broken diagonal line (control) represents data when noise was absent.

doses and then averaged for successive intervals 3 through 8. The first two intervals were omitted from the data analysis due to warm-up effects. The last two intervals were omitted because the rate-altering effects of cocaine began to diminish during the last two intervals of a session (time-course effects). A plot of these overall mean response rates versus dose describes the range of effects due to cocaine administration (Figure 6). The overall mean rate was expressed as a percentage of control rate and was plotted on the y axis. Drug dose was plotted on the x axis using a logarithmic scale. For all subjects, the dose-effect functions could be characterized as inverted U-shaped curves. The lowest dose of cocaine (0.03 mg/kg) had little effect on mean response rate, and the intermediate doses (0.1 to 0.3 mg/kg) increased rate for all subjects. The maximum rate increase occurred at a dose of 0.3 mg/kg for subjects S-60 and S-76 and at 0.56 mg/kg for subject S-78. The highest

dose administered (1.0 mg/kg) decreased response rate below saline level for all subjects and produced erratic performance characterized by alternating periods of responding and pausing throughout the interval.

The effects of cocaine were also evident in the IRT distributions derived from performance under the FI schedule. The high relative frequency of IRTs exceeding the upper limit of the distribution indicated frequent pauses of long duration during control sessions (Figure 7, top). Following the administration of 0.56 mg/kg cocaine, there was a shift toward briefer and more uniform IRTs and the relative frequency of IRTs exceeding the upper limit of the distribution was markedly reduced (Figure 7, bottom). Each of the distributions in Figure 7 was derived from a single representative session and is not the result of averaging across sessions.

To quantify further the changes in performance due to cocaine dose, response rate in

Fig. 5. Cumulative records showing effects of cocaine dose on responding of one squirrel monkey (S-76) under an FI 300-s stimulus-shock termination schedule. Otherwise, as in Figure 1.

each of ten 30-s segments of each FI was calculated and then averaged for intervals 3 through 8. Drug rate for each segment was plotted against the corresponding control rate on logarithmic axes, and a linear regression line was determined using a least squares estimate. Comparison of drug rate versus control rate for each dose of cocaine showed that there was an orderly decrease in the slope of the regression line for all subjects as drug dose increased from 0.03 mg/kg to 0.56 mg/kg (Table 2). Individual regression lines for each subject revealed that the decrease in slope was due to increases in the low baseline response rates that were characteristic during the early

segments of the interval (Figure 8). The higher response rates during the later segments of the interval were either unchanged (Subjects S-60 and S-76) or slightly increased (Subject S-78). Response rate following drug administration versus control rate was compared for individual subjects, and the mean of the data points comprising the regression line with a slope closest to zero was defined as the most constant rate for that subject under that set of conditions. A dose of 0.56 mg/kg cocaine produced the greatest change and yielded a slope closest to zero for Subjects S-60 and S-78. A dose of 1.0 mg/kg cocaine produced a slope closest to zero for Subject S-76, but the dose-effect curve (Figure 6) indicated that 1.0 mg/kg decreased response rate below control rate. Therefore, the regression line determined for a dose of 0.56 mg/kg was considered the point at which a most constant rate was produced for all subjects. Using these criteria, the most constant rate was 0.38, 1.11, and 0.56 responses per second for Subjects S-60, S-76, and S-78, respectively. Comparing these cocaine data with those obtained with white noise, the most constant rate obtained following cocaine administration (0.38, 1.11, and 0.56 responses per second) was lower for all subjects than that obtained with white-noise presentation (0.45, 1.65, and 1.07 responses per second).

Effects of Cocaine and White Noise Presented Together

In order to investigate the interaction of cocaine with noise as a nondrug stimulus, selected doses were presented in combination. To quantify the effect, response rate in each of ten 30-s segments of each FI was calculated and then averaged for successive FI intervals 3 through 8. Response rate during each of these segments after treatment was plotted against corresponding control rate on logarithmic axes, and a linear regression line was determined using a least squares estimate. Table 3 shows mean response rate and slope of regression lines for doses of 0.03 and 0.56 mg/kg cocaine in combination with 76 dB and 80 dB white noise. The rates obtained for white noise (80 dB) and cocaine (0.56 mg/kg) presented in combination (0.43, 1.18, and 0.70 responses per second) were intermediate between the values obtained for either 80 dB white noise (0.45, 1.65, and 1.07 responses

Fig. 6. Effect of cocaine dose on overall mean response rate for a group of 3 monkeys (top left) and for individual subjects. Cocaine's effect is expressed as percentage of the mean response rate obtained when saline was injected (100% = control). Bars indicate $\pm$ one standard deviation.

per second) or 0.56 mg/kg cocaine (0.38, 1.11, and 0.56 responses per second) alone. The rates obtained when 0.56 mg/kg cocaine was combined with 76 dB white noise (0.30, 0.83, and 0.56 response per second) were lower than those obtained when 0.56 mg/kg cocaine was administered alone. Similarly, the rates obtained when 80 dB white noise was combined with 0.03 mg/kg cocaine (0.45, 1.33, and 0.31 responses per second) were lower than those obtained with 80 dB white noise alone in 2 of 3 subjects (S-76 and S-78). The slope of the regression line for 80 dB white noise plus 0.03 mg/kg cocaine was also greater than the slope for 80 dB white noise alone for Subjects S-76 (0.24 vs. 0.14) and S-78 (0.85 vs. 0.13). Thus, a dose of cocaine (0.03 mg/kg) that had a moderate effect when administered alone reduced response rate and increased the slope obtained with 80 dB white noise in 2 of 3 subjects. Similarly, an intensity of white noise (76 dB) that had a moderate effect when presented alone decreased the constant rate produced by 0.56 mg/kg cocaine in all subjects.

When 80 dB white noise and 0.56 mg/kg cocaine were presented in combination, the uniform rate obtained was intermediate between the value obtained for either 80 dB white noise or 0.56 mg/kg cocaine alone.

DISCUSSION

The effects of white-noise presentation and cocaine administration on FI performance were similar for all subjects in the present experiment. Both stimuli produced effects that can be characterized as supportive of the concept of rate constancy. During white-noise (76 dB to 80 dB) presentation and following cocaine (0.03 to 0.56 mg/kg) administration, overall response rate was increased, the pause at the beginning of the interval was shortened, and the pattern of positively accelerated responding engendered by the FI schedule became less curvilinear. There was a corresponding shift toward briefer and more uniform IRTs, and the relative frequency of IRTs exceeding the upper limit of the distri-

Fig. 7. Effect of cocaine dose on interresponse time (IRT) distributions for individual subjects. Each distribution is derived from fixed intervals 3 to 8 of a single session. N = total number of responses emitted for each distribution.

bution was markedly reduced. The linear regression analysis of response rates during 30-s segments of the FI revealed that the change toward a more uniform rate was due to increases in response rates during the early segments of the interval whereas higher response rates during the later segments of the interval were either unchanged or slightly increased. The similarities in rate-altering effects of white noise and cocaine provide further evidence in support of McKim's (1981) proposal that rate-related drug effects may be, in part, a result of their ability to act as extraneous stimuli.

Several workers (e.g., Ksir, 1976; McKim, 1973, 1981; Webbe, 1981) have suggested that rate-related effects could be produced by white noise and, in the present study, the results obtained with white noise and with cocaine were qualitatively similar at every level of analysis. White-noise presentation produced reproducible effects even though noise was presented as frequently as twice per week during the course of the study. Habituation to auditory stimuli, defined as differential responsiveness to new and old stimuli, is well

documented for response measures as varied as the startle response in the rat (Davis & Wagner, 1968, 1969), evoked peripheral vasomotor activity in rabbits (Whitlow, 1975), heart rate in newborn human infants (Bridger, 1961) and sucking in newborn human infants (Keen, 1964). Nevertheless, in the present study, white noise was presented twice per week for several consecutive weeks with no discernible decrements in its effects.

The method of white-noise presentation may have been important for the persistent effects observed. None of the subjects had been exposed to white noise for at least 6 months prior to the present experiment. The sequence of stimulus presentation was white noise alone, cocaine alone, and then white noise combined with cocaine. This allowed 10 weeks to elapse between presentation of the first and second blocks of white noise. However, the most important aspect of the procedure may have been the variation in noise intensity. Habituation procedures have been used to test for discrimination of stimulus change, demonstrating that an habituated response can be sensitive to variation in stimulus intensity (Bridger, 1961,

Fig. 8. Effect of cocaine doses (mg/kg) on mean response rate during individual 30-s segments of an FI 300-s schedule for individual subjects. Response rate for each segment is the mean for fixed intervals 3 to 8. Otherwise, as in Figure 4.

1962; Keen, 1964). The presentation of different intensities in the present experiment may have decreased the likelihood that habituation to the white-noise stimulus would occur.

Prior to the present experiment, all subjects had performed under a random-interval (RI) stimulus-shock-termination schedule with 85 dB white noise used as a masking stimulus. Because the RI schedule engendered a relatively constant rate of responding, it is possible that the white noise in the present study served to reinstate the pattern of responding that had previously occurred in its presence. However, if the effects of white noise depended entirely on the reinstatement of RI performance, the most nearly constant rate produced by white noise in the present experiment should be similar to the rate obtained during previous RI performance. Mean responses during the last 10 sessions of RI performance were 0.72, 0.47, and 0.70 response per second for Subjects S-60, S-76, and S-78, respectively. The most nearly

constant rates produced by white noise in the present study were 0.45, 1.07, and 1.65 responses per second for Subjects S-60, S-76, and S-78, respectively. Clearly, the uniform rates produced by white noise in the present study differ from those that would be expected if white noise had simply reinstated previous RI performance. Precautions were also taken to minimize the influence of the previous RI schedule. None of the subjects had been used in an experiment for over 6 months prior to the present study, and during FI training with white noise absent, each subject was exposed to 126 two-hour sessions and to an additional 79 one-hour sessions to ensure stable FI performance before testing with white noise began.

Interactions were obtained for all subjects when white noise and cocaine were presented in combination. Perhaps the most interesting interaction was that the most constant rate determined for white noise (80 dB) and cocaine (0.56 mg/kg) in combination was inter-

Table 2

Effect of cocaine dose on fixed-interval performance in three squirrel monkeys. *Rate* corresponds to the overall mean rate of responding (responses per second) during a session. *Slope* was derived from a linear regression analysis of local response rates during 30-s segments of the FI 300-s schedule when rate after cocaine administration was plotted relative to rate without cocaine.

Dose (mg/ kg)	Squirrel monkey					
	S-60		S-76		S-78	
	Rate	Slope	Rate	Slope	Rate	Slope
0.03	.25	.87	1.19	.69	.27	.33
0.1	.39	.45	1.75	.44	.36	.25
0.3	.45	.35	1.78	.33	.54	.19
0.56	.38	.15	1.11	.21	.56	-.05
1.0	.15	.24	.33	.08	.17	-.05

mediate between that obtained for either white noise or cocaine alone. In addition, a dose of cocaine (0.03 mg/kg) that had a moderate effect when administered alone reduced maximum response rate and the slope of the regression line obtained with 80 dB white noise for 2 of the 3 subjects. Similarly, an intensity of white noise (76 dB) that had a moderate effect when presented alone reduced the constant rate produced by 0.56 mg/kg cocaine for all subjects. These results indicated that white noise and cocaine may have produced their effects through a common behavioral mechanism of action—for example, a nonspecific disruption of behavior due to the presentation of an extraneous environmental stimulus.

Of course, white noise and cocaine may have interacted through other, more direct mecha-

nisms of action. Lindsley (1961) postulated that variations in the arousal level of an organism would influence ongoing perceptual processes, and Isaac and DeVito (1958) suggested that behavioral arousal can be manipulated by altering ambient sensory conditions. *d*-Amphetamine, a behavioral stimulant with a pharmacological mechanism of action similar to that of cocaine, has been shown to reduce the arousal effects of increased ambient illumination (Alexander & Isaac, 1965), to elevate visual thresholds (Thurmond, 1965) in the macaque monkey, and to elevate auditory thresholds in the squirrel monkey (Delay, Steiner, & Isaac, 1979). It is possible that the interactions of cocaine and white noise observed in the present study occurred through a drug-induced change in the sensitivity of the auditory system. Whatever the basis of the interaction, studies of the manner in which white noise and cocaine interact may help elucidate the behavioral mechanisms responsible for rate-related effects of environmental stimuli.

An obvious difference between the effects of cocaine and white noise was the rate at which responding became constant. For all subjects, white noise produced a most constant rate greater than that obtained for cocaine. Although the change in control rate for Subject S-78 makes this a difficult comparison, control rates for Subjects S-60 and S-76 were stable throughout the experiment and the results were consistent for all subjects. These results indicate that rate constancy can be produced by drug and nondrug stimuli, and that the rate at which responding becomes most nearly

Table 3

Effect of two doses of cocaine in combination with 76 dB or 80 dB white noise on mean response rate and slope of the linear regression line in 3 squirrel monkeys. *Rate* corresponds to the overall mean rate of responding (responses per second) during a session. *Slope* was derived from a linear regression analysis of local response rates during 30-s segments of the FI 300-s schedule when rate during treatment was plotted relative to rate without treatment.

Drug dose (mg/kg) and Sound intensity (dB)	Squirrel monkey					
	S-60		S-76		S-78	
	Rate	Slope	Rate	Slope	Rate	Slope
0.56 mg/kg alone	.38	.15	1.11	.21	.56	-.05
0.56 mg/kg + 76 db	.30	.08	.83	-.04	.51	-.02
0.56 mg/kg + 80 db	.43	-.01	1.18	-.10	.70	-.07
80 db alone	.45	.27	1.65	.14	1.07	.13
80 db + 0.03 mg/kg	.45	.27	1.33	.24	.31	.85
80 db + 0.56 mg/kg	.43	-.01	1.18	-.10	.70	-.07

constant may depend upon the type and intensity of the stimulus being presented. Description and interpretation of data of this type emphasize the value of the rate-constancy concept in characterizing the effects of various environmental stimuli on behavior. Both cocaine and white noise yielded relatively constant and uniform responding at appropriate doses or intensities, and the constancy of rate was quantified. Yet, it was possible to differentiate between the two types of stimulation based on differences in the rate at which constant responding occurred. The ability to describe and to quantify differences in behavioral effects in this manner can be valuable in efforts to identify similarities in mechanisms underlying the behavioral effects.

If rate-related drug effects resulted only from the ability of drugs to act as extraneous stimuli, then all behaviorally active drugs might be expected to produce similar effects. There are, however, examples of rate-related drug effects that are specific to particular classes of pharmacologic agents (e.g., Barrett, 1985; McMillan, 1973; Robbins, 1981). Even though cocaine and white noise appeared to produce rate-related effects through a common mechanism of action, the rate at which responding became constant was different for the two stimuli. It is possible, therefore, that rate-related drug effects may result from a combination of nonspecific disruption of behavior due to stimulus change produced by drug administration and drug-specific effects not observed for all stimuli. The manner in which drug stimuli interact with nondrug stimuli other than white noise should help determine the relative role played by specific and nonspecific stimulus effects of pharmacological agents.

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