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RELATIVE REINFORCER MAGNITUDE UNDER A NONINDEPENDENT CONCURRENT SCHEDULE OF COCAINE REINFORCEMENT IN RHESUS MONKEYS[1]

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Lever pressing by three rhesus monkeys was maintained under a two-lever concurrent schedule of cocaine reinforcement. Responding on one lever (constant-dose lever) produced a constant dose of 0.05 or 0.1 mg/kg/injection arranged according to a variable-interval 1-min schedule. Responding on the other lever (variable-dose lever) produced a comparison dose of cocaine (0.013 to 0.8 mg/kg/injection), also under a variable-interval 1-min schedule. The two variable-interval schedules were made nonindependent by arranging that the assignment of a reinforcer by one schedule inactivated the second schedule until the assigned reinforcer had been obtained. This modification ensured that the two cocaine doses were obtained with approximately equal frequency, regardless of the distribution of the subject's responding. Preference, indicated by relative response frequency on the variable-dose lever, was almost always for the larger of the doses and was a monotonic function of the comparison dose, except at the highest doses. Preferences at the highest comparison doses may have resulted from the low overall response rates exhibited at these doses. Relative response frequencies on the variable-dose lever roughly matched relative reinforcer magnitude (mg/kg/injection available on the variable-dose lever divided by the sum of mg/kg/injections available on each lever).

Key words: concurrent schedules, cocaine reinforcement, choice behavior, relative reinforcer magnitude, relative response rates, response rates, variable-interval schedules of reinforcement, lever press, rhesus monkeys

In a study by Iglauer and Woods (1974), rhesus monkeys preferred the larger of two simultaneously available cocaine doses. Each dose was associated with a specific lever and was made available according to a variable-interval (VI) 1-min schedule. Both variable-interval schedules operated concurrently and independently. The measure of preference for a dose was the relative response frequency exhibited on the lever associated with that dose.

Under this procedure, Iglauer and Woods also observed approximate equality (matching) between the relative response frequency on a lever and the relative drug intake obtained on that lever. Their findings thus extend to a new reinforcer the generality of a relationship previously demonstrated with respect to a number of different parameters of nutritive reinforcement (Brownstein, 1971; Catania, 1963*a*; Chung and Herrnstein, 1967; Herrnstein, 1961; Hursh and Fantino, 1973; Ten Eyck, 1970).

A striking feature of the Iglauer and Woods data was the frequent occurrence of exclusive preferences for the higher cocaine dose. In such cases, the relative frequency of responding on one lever exceeded 0.99, and/or all reinforcements were obtained on only one lever. Such exclusive preferences were an extreme case of a more general occurrence, for comparisons in which two different doses were available, of a marked inequality in the number of reinforcers obtained via each lever. Similar extreme differences in reinforcer distribution have not been reported in most previous studies in which different magnitudes of nutritive reinforcers have been available under equal-valued concurrent schedules (Brownstein, 1971; Catania, 1963*b*; Fantino, Squires, Delbrück, and Peterson, 1972; Walker

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and Hurwitz, 1971). In the Iglauer and Woods study, dose was held constant on one lever and various comparison doses were tested on the other lever, with the intent of ranking the comparison doses with respect to their reinforcing efficacy. However, the occurrence of exclusive preferences led to a difficulty in interpretation of the results, since if two doses were each exclusively preferred to the standard dose, it was impossible to state the reinforcing efficacy of these two doses relative to each other. Nevertheless, it was also true that monkeys' preferences were sensitive to differences of as little as 0.017 mg/kg/injection between the constant dose and the dose on the other lever.

In the present study, the two concurrent VI 1-min schedules no longer operated independently. Assignment of a reinforcer by one variable-interval schedule resulted in cessation of both variable-interval schedules until after the assigned reinforcer had been obtained (Stubbs and Pliskoff, 1969). In this manner, the distribution of reinforcement was fixed so that approximately equal numbers of each available dose were delivered in each session. The intent of this modification was to maintain the sensitivity of the concurrent-schedule procedure and at the same time to obtain preferences that were graded according to the difference between the doses. With the exception of this modification, the schedule conditions of the present study were the same as those of Iglauer and Woods (1974; p. 181-182).

METHOD

Subjects

Boris, Rico, and Rodney, three male rhesus monkeys (*Macaca mulatta*) weighing between 5 and 7 kg, served in daily experimental sessions; they were housed individually and allowed unlimited access to water. Twice-daily feedings of 15 Purina Monkey Chow biscuits, treated by the manufacturer with 608 g/ton isoniazid for the prevention of tuberculosis, were supplemented once or twice weekly with fresh fruit. Rico and Boris had both served in the Iglauer and Woods (1974) study, and had had several months' experience under concurrent-schedule dose-choice procedures involving intravenous injections of cocaine; Rodney was experimentally naive. Boris died during the latter half of the study.

Surgical Preparation

Rico and Boris had already been catheterized with a silicone rubber catheter (Rodhelm Reiss Inc., Belle Mead, New Jersey; outer diameter = 0.24 cm, inner diameter = 0.079 cm). Rodney was similarly prepared at the start of the study. Under ketamine hydrochloride anesthesia (30 mg/kg, intramuscularly delivered), a catheter was implanted in a femoral vein, with the tip terminating at approximately the level of the right atrium. The distal end of the catheter ran subcutaneously to a midscapular point, where it exited through a stab wound. Details of the catheterization procedure have been described elsewhere (Deneau, Yanagita, and Seevers, 1969; Yanagita, Deneau, and Seevers, 1965). Whenever a monkey's catheter became dysfunctional or was removed by the monkey, another catheter was implanted, under the same procedure, in an internal jugular or femoral vein.

Apparatus

Each monkey was housed in an enclosed, sound-insulated wooden chamber 64 cm wide, 70 cm high, and 77 cm deep. Ventilation was provided by an exhaust fan mounted outside on the top of the chamber. The floor was a metal grid, with a metal pan containing wood shavings mounted below. A water bottle was located on one outside wall, with a drinking tube projecting into the chamber; a food dish was located on the opposite inside wall. General illumination was provided by two 6-W white light bulbs mounted in a clear Plexiglas box overhead.

A hollow, jointed metal extension arm, mounted on the rear wall, was attached to a metal harness worn by the monkey, allowing relatively free movement (Deneau *et al.*, 1969). A sterile piece of catheter contained in the restraining apparatus was connected at one end to the external tip of the implanted catheter by means of a metal juncture. The other end of this piece of catheter was attached to the stem end of a Y-connector (Becton-Dickinson #3091) which, in turn, was connected to two syringe infusion pumps (Sage #255-1 or Harvard #1100) by two additional pieces of catheter.

An aluminum chassis, 30.5 cm wide, 20.5 cm high, and 7.5 cm deep, was mounted at approximately the center of the inside of

the front door. On the front of the chassis were mounted three response levers (Lehigh Valley Electronics #1380) requiring a downward force of 0.49 N for operation. Two side levers were located 2 cm from the bottom of the chassis and 16 cm apart. Centered 4.1 cm above each side lever was a circular aperture 2.9 cm in diameter, covered by translucent Plexiglas. A 6-W green Christmas-tree light positioned behind the Plexiglas could transilluminate the left lever; a 6-W red Christmas-tree light, the right lever. The third (center) lever was mounted midway between the two side levers and 7 cm above them. It could be illuminated by a 6-W yellow pilot light located 4.1 cm above it. A pair of 6-W blue Christmas-tree lights mounted in the Plexiglas box overhead provided an alternate houselight condition. During experimental sessions, white masking noise (approximately 70 dB re 0.0002 dynes/cm^2) was continuously present.

Standard electromagnetic relay equipment automatically controlled stimulus conditions, scheduling and delivery of reinforcers, and acquisition of data. Responses, reinforcements, and time intervals were recorded by digital counters and by a six-channel event recorder (Ralph Gerbrands Company, #PC-2).

Drugs and Dosage

Cocaine hydrochloride was dissolved in 0.9% saline solution and diluted to the desired concentration; all doses are expressed as the salt. Drug dosage per injection, for a given monkey, was manipulated by varying the volume of a constant-concentration solution injected over a constant period of time. These variations were accomplished by the use of different pump motor speeds and, if necessary, different syringe sizes. The constant-concentration solutions for Rico and Rodney resulted in delivery of a dose of 0.1 mg/kg in a 0.375-ml injection. For Boris, the constant-concentration solution resulted in delivery of a dose of 0.05 mg/kg in the same volume.

Procedure

Schedule specification. The terminal contingencies were presented directly to Boris and Rico following their final dose comparison in the Iglauer and Woods (1974) study. For Rodney, who was experimentally naive, the terminal contingencies were gradually approached, following initial training in which responding was reinforced by 0.1 mg/kg injections of cocaine. During this initial training, each response on either side lever resulted in delivery of a reinforcer.

A schematic diagram of the terminal schedule conditions is shown in Figure 1. Sessions consisted of repeating cycles of four conditions. Each cycle began with illumination of the yellow center-lever light and of the white houselight overhead (Condition 1). In the presence of these stimulus conditions, depression of the center lever (fixed ratio 1) turned off the yellow center-lever light and turned on the green and the red side-lever lights. In the presence of the white houselight and the red

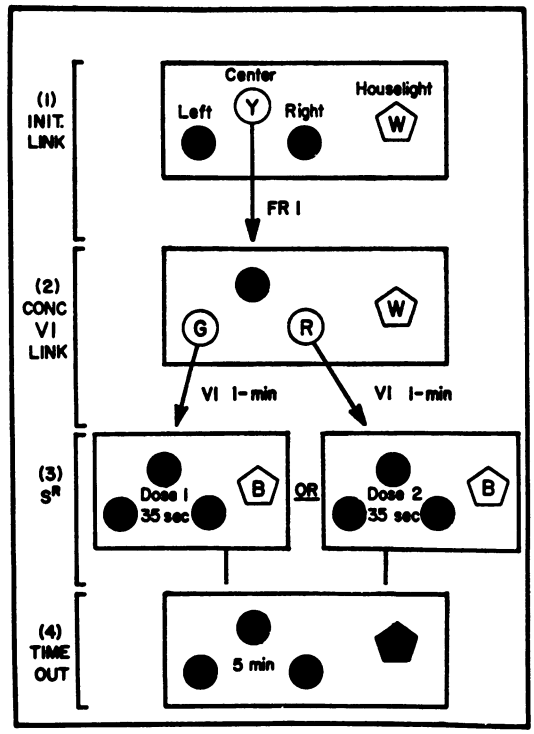

Fig. 1. Diagram of one cycle of the procedure. Each box represents one possible state. Numbers on the left refer to successive experimental conditions. At the start of a cycle, the yellow center-lever light and white houselight are illuminated, and the side-lever lights are dark (Condition 1). A single center-lever response extinguishes the center-lever light and turns on the green and red side-lever lights (Condition 2). Responding on either side-lever during the concurrent VI 1-min VI 1-min link leads to injection of one of two drug doses (Condition 3). During reinforcement, the houselight is blue and all lever lights are darkened. A 5-min timeout of total darkness follows reinforcement (Condition 4), after which the initial-link conditions are re-instated.

Table 1

Summary of dose-comparison data. Doses on the variable-dose lever are listed for each monkey in the order of their presentation (Column 2). The lever of the constant dose, and therefore the sequence to which a determination belongs, is indicated in Column 3. Data values in Columns 5, 6, 7, 10, and 11 are averages from the five criterion sessions at each determination. Column 9 gives the absolute values of the deviations of relative response frequency (Column 7) from relative dose (Column 8). Note that fewer than 15 sessions were required for Boris at a comparison dose of 0.1 mg/kg/injection. For this monkey, the last comparison of Iglauer and Woods (1974) also involved a comparison dose of 0.1 mg/kg/injection and took place immediately before the present comparison.

				Abs. Resp. Rates (Resp/Sec)		*Relative with Respect to Var.-Dose Lever*		*Abs. Deviat. from Matching*	*Average Latency to Center-Lever Response (sec)*	
Monkey (1)	*Var. Dose (mg/kg/inj)* (2)	*Const.-Dose Lever* (3)	*No. of Sessions* (4)	*Var. Lever* (5)	*Const. Lever* (6)	*Resp. Freq.* (7)	*Dose* (8)	*(|8 − 7|)* (9)	*After Var. Dose* (10)	*After Const. Dose* (11)
RICO	0.4	L	23	0.26	0.07	0.80	0.80	0.00	4	3
(Const. dose	0.025	L	18	0.08	0.63	0.11	0.20	0.09	9	9
0.1 mg/kg/inj)	0.2	L	15	0.54	0.10	0.83	0.67	0.16	4	3
	0.05	L	39	0.05	0.13	0.27	0.33	0.06	9	7
	0.1	L	62	0.29	0.26	0.52	0.50	0.02	10	10
	0.8	L	34	0.02	0.03	0.46	0.89	0.43	265	35
	0.025	R	18	0.05	0.39	0.11	0.20	0.09	3	5
	0.4	R	45	0.13	0.05	0.75	0.80	0.05	3	2
	0.05	R	34	0.19	0.98	0.17	0.33	0.16	2	4
	0.2	R	17	0.56	0.11	0.83	0.67	0.16	3	2
	0.8	R	20	0.06	0.03	0.70	0.89	0.19	67	16
	0.1	R	30	0.28	0.42	0.41	0.50	0.09	8	9
BORIS	0.1	L	7	0.79	0.22	0.78	0.67	0.11	3	3
(Const. dose	0.025	L	21	0.30	0.34	0.47	0.33	0.14	31	28
0.05 mg/kg/inj)	0.2	L	15	0.37	0.09	0.80	0.80	0.00	5	4
	0.4	L	15	0.15	0.04	0.80	0.89	0.09	39	4
	0.0125	L	15	0.41	0.65	0.38	0.20	0.18	23	20
	0.05	L	58	0.29	0.24	0.55	0.50	0.05	7	6
	0.025	L	30	0.18	0.24	0.43	0.33	0.10	6	4
	0.05	R	36	0.43	0.46	0.48	0.50	0.02	7	8
	0.2	R	15	1.13	0.18	0.86	0.80	0.06	2	2
RODNEY	0.1	R	53	0.15	0.14	0.51	0.50	0.01	25	21
(Const. dose	0.05	R	16	0.11	0.57	0.17	0.33	0.16	12	8
0.1 mg/kg/inj)	0.2	R	60	0.32	0.11	0.73	0.67	0.06	38	29
	0.025	R	31	0.05	0.49	0.10	0.20	0.10	16	13
	0.4	R	23	0.15	0.06	0.69	0.80	0.11	67	39
	0.8	R	16	0.07	0.02	0.75	0.89	0.14	380	55

and green side-lever lights, the concurrent variable-interval component was in effect (Condition 2). In this component, two variable-interval tape timers operated concurrently and arranged the availability of two cocaine doses. One dose was associated with the left lever; the second dose with the right lever. The average interreinforcement interval arranged by each schedule was 1 min. When a reinforcer became available on one lever, both variable-interval timers were inactivated and remained so until a center-lever response initiated the concurrent variable-interval component in the next cycle.

A reinforced response on one of the side levers resulted in: (a) darkening of the red and green side-lever lights and of the white houselight; (b) operation of the appropriate infusion pump for 35 sec; and simultaneously, (c) illumination of a blue houselight for 35 sec (Condition 3). Following reinforcement, a 5-min timeout occurred during which all stimulus lights were darkened (Condition 4). At the end of this period, a new cycle began. No scheduled consequence followed responses on any of the three levers during the reinforcement or timeout periods. Sessions ended after the thirtieth reinforcement.

Changeover delay (COD). When a monkey switched (changed over) from one side-lever to the other, the first response on the switched-to lever was ineligible for reinforcement, as were all responses on this lever during the next 1.5 sec. In addition, when a right-lever response and a left-lever response occurred simultaneously, neither response was reinforced. Following simultaneous responding, the next single response on either side-lever was ineligible for reinforcement and also initiated a 1.5-sec COD period. The first variable-interval response in a cycle never resulted in a COD and was always eligible for reinforcement.

Dose variations. For each monkey, one lever was designated the constant-dose lever. The cocaine dose associated with this lever was 0.1 mg/kg/injection for Rico and Rodney, and 0.05 mg/kg/injection for Boris. The other lever was designated the variable-dose lever, and the comparison dose associated with this lever (the variable dose) was changed according to the criteria outlined below. Values of the comparison dose presented to each monkey and their order of presentation are shown in Column 2 of Table 1.

For each monkey, a sequence of determinations consisted of all the dose comparisons in which a given lever was the constant-dose lever; within a sequence, comparisons were occasionally repeated. For Rico and Boris, following the first sequence of determinations, the constant- and variable-dose levers were reversed, and a second sequence of determinations was begun. Boris's second sequence was not completed before the monkey died.

Criteria for dose variation. The first 10 sessions in which a given value of the comparison-dose was presented were disregarded. In subsequent sessions, the relative frequency of responding on each lever was computed daily and behavior was considered stable if over five consecutive sessions, (a) the range of relative response frequencies on either lever did not exceed 0.10, and (b) there was no systematic trend in the relative response frequency measure. When these criteria were satisfied, the comparison dose was changed in the following session. The number of consecutive sessions at each determination is indicated in Column 4 of Table 1.

Analysis of data. Absolute response rate on a side lever was calculated by dividing the total number of responses on that lever in the variable-interval component by the total variable-interval time. To calculate relative response frequency on the variable-dose lever, the total number of responses on the variable-dose lever during the variable-interval component was divided by the sum of the responses on the variable- and constant-dose levers during that component.

Relative dose (*i.e.,* relative reinforcer magnitude) was computed by dividing the variable dose size by the sum of the variable-dose and the constant-dose sizes. All measures presented were calculated for each of the five criterion sessions of a determination and then averaged across these sessions.

RESULTS

Concurrent Variable-Interval Performances

With comparison doses lower than the constant dose, relative response frequencies on the variable-dose lever were less than 0.5 (Figure 2, left side; Table 1, Column 7). With comparison doses greater than the constant dose, relative response frequencies on the variable-dose lever were greater than 0.5. Thus, the

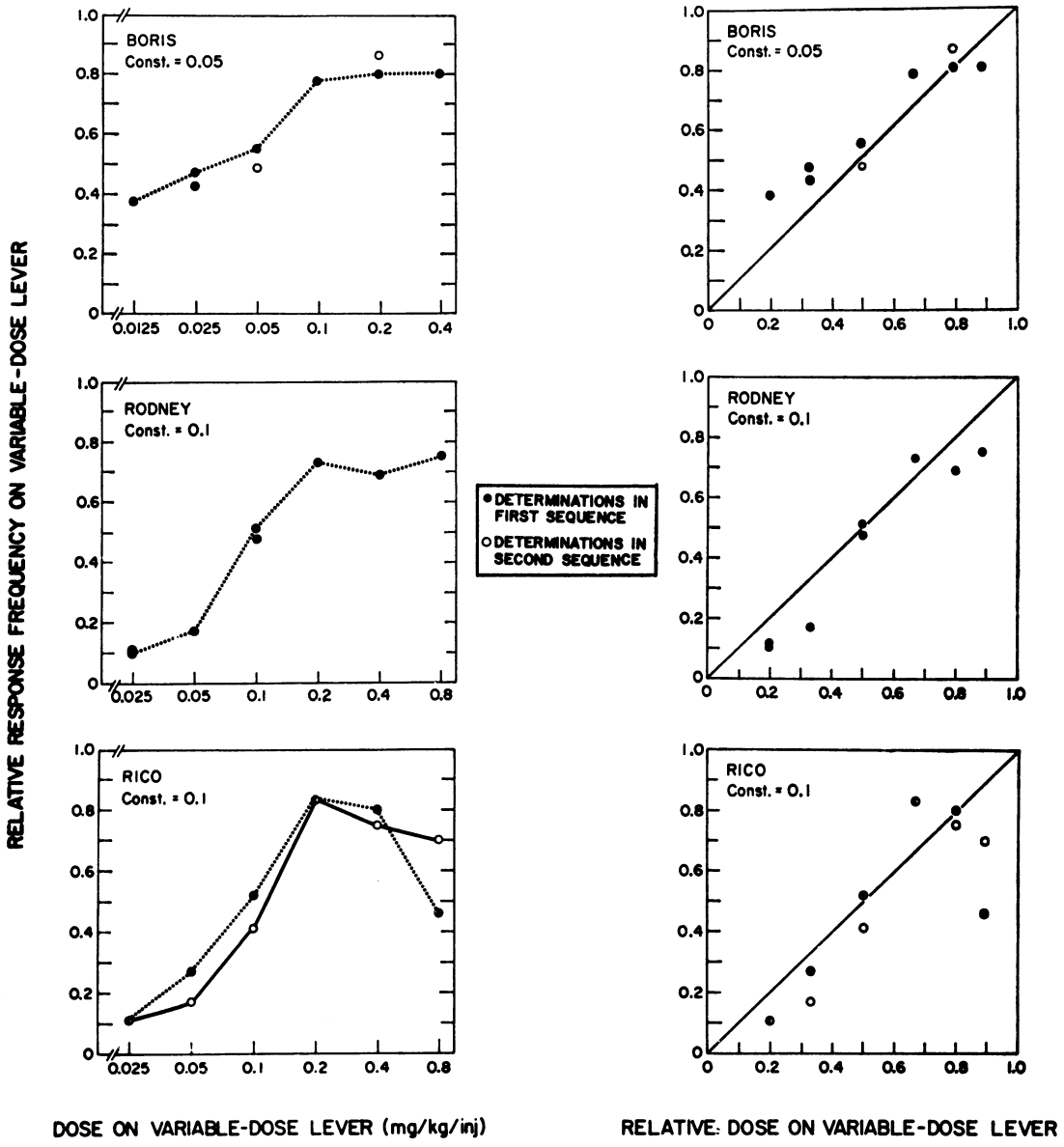

Fig. 2. Left side: relative response frequency on the variable-dose lever as a function of dose on this lever. Doses are logarithmically spaced. The constant dose is indicated on each graph under the monkey's name. Data are the means of the five criterion sessions at each determination. With repeated determinations in a sequence, only the first is joined to the line. Right side: relative response frequencies on the variable-dose lever plotted against relative dose magnitude on the variable-dose lever. The constant dose is indicated on each graph under the monkey's name. Relative dose on the variable-dose lever is the dose available on this lever divided by the sum of the doses available on both levers. The diagonal line represents the locus of perfect matching. Data are the means of the five criterion sessions at each determination.

higher of the two doses available was always the preferred. When the variable dose was equal to the constant dose, the relative response frequency on the variable-dose lever was approximately 0.5 for all three subjects.

As the dose on the variable-dose lever was increased, preference for this dose increased up to the dose just larger than the constant dose (*i.e.*, in the case of Boris, 0.1 mg/kg/inj; in the case of the other two monkeys, 0.2 mg/kg/inj).

At still higher doses, no consistent increase in preference occurred.

In the right side of Figure 2, monkeys' relative response frequencies on the variable-dose lever are now plotted as a function of relative dose on this lever. Perfect matching, or equality between the measures, is represented by the solid diagonal line. Relative response frequency approximately matched relative magnitude of reinforcement: most data points lay quite close to the line of perfect matching. Absolute deviations from matching (Table 1, Column 9) were averaged across determinations for each monkey. The mean absolute deviation from matching was 0.08 for Boris, 0.09 for Rodney, and 0.12 for Rico. However, Rico's mean absolute deviation was inflated by one exceptionally large deviation from matching, *viz* that of the first-sequence determination with a variable dose of 0.8 mg/kg/inj. Exclusion of this point from the calculations yields a mean absolute deviation of 0.10.

Absolute rates of responding. Absolute response rates on each lever are presented in Table 1 (Columns 5 and 6). In the lower sections of the graphs in Figure 3, these data are plotted for each monkey as a function of the dose on the variable-dose lever. In general, absolute response rate on the variable-dose lever first increased with the dose available on this lever and then decreased at higher doses, the peak rate occurring at the dose just above the constant dose. Absolute response rate on the constant-dose lever usually decreased as the dose on the variable-dose lever increased. Departures from these general tendencies occasionally occurred but only at lower comparison doses. Changes in relative response frequency on the variable-dose lever therefore reflected changes in the absolute rates of responding on both levers.

Mean overall variable-interval response rates for each monkey are averaged across determinations (when more than one determination was made) and are presented in the upper sections of the graphs in Figure 3. For any dose comparison, the range of overall rates that a monkey exhibited across determinations may be obtained from the lower section of its graph, since the overall rate for any determination is the sum of the rates on the two levers. Considerable variability in response rates was apparent between repeated determinations of a given dose comparison. In the lower portion of the dose range, overall response rate was either independent of comparison dose or declined as the comparison dose increased. However, at higher doses (greater than 0.1 mg/kg/inj for Boris and greater than 0.2 mg/kg/inj for Rico and Rodney), mean overall response rates consistently declined as dose on the variable-dose lever increased. At the highest comparison doses presented, overall response rates were always less than 0.2 responses per second and usually less than 0.1 responses per second.

Hourly drug intake was an increasing function of the comparison dose. As the upper sections of the graphs in Figure 3 show, the lowest overall variable-interval rates of responding were associated with the highest rates of drug intake.

Latencies. For each monkey, mean latency to respond on the center lever after a variable-dose injection was usually approximately equal to the latency to respond after a constant-dose injection (Table 1, Columns 10 and 11). Exceptions to this rule were observed at the highest comparison doses presented. With Rico, for example, the mean latency to respond after an injection of 0.8 mg/kg was four to eight times greater than the latency to respond after a constant-dose injection of 0.1 mg/kg in the same session. Similar differences in latencies following the constant and variable doses were seen in Rodney at comparison doses of 0.4 or 0.8 mg/kg/inj and in Boris when the comparison dose was 0.4 mg/kg/inj. Apart from these cases, latency appeared unrelated to the preceding dose.

DISCUSSION

In the present procedure, the independence of the two concurrently operating variable-interval schedules was constrained to ensure delivery of equal numbers of injections via each schedule; monkeys reliably preferred the larger doses of cocaine. If relative response frequency on the variable-dose lever is taken as a measure of the reinforcing efficacy of the comparison dose, relative to the constant dose, it may be concluded that the larger of the two doses of cocaine is the more reinforcing. In this respect, the present findings confirm those of Iglauer and Woods, in whose procedure the two variable-interval schedules were independent. Further support for this conclusion is

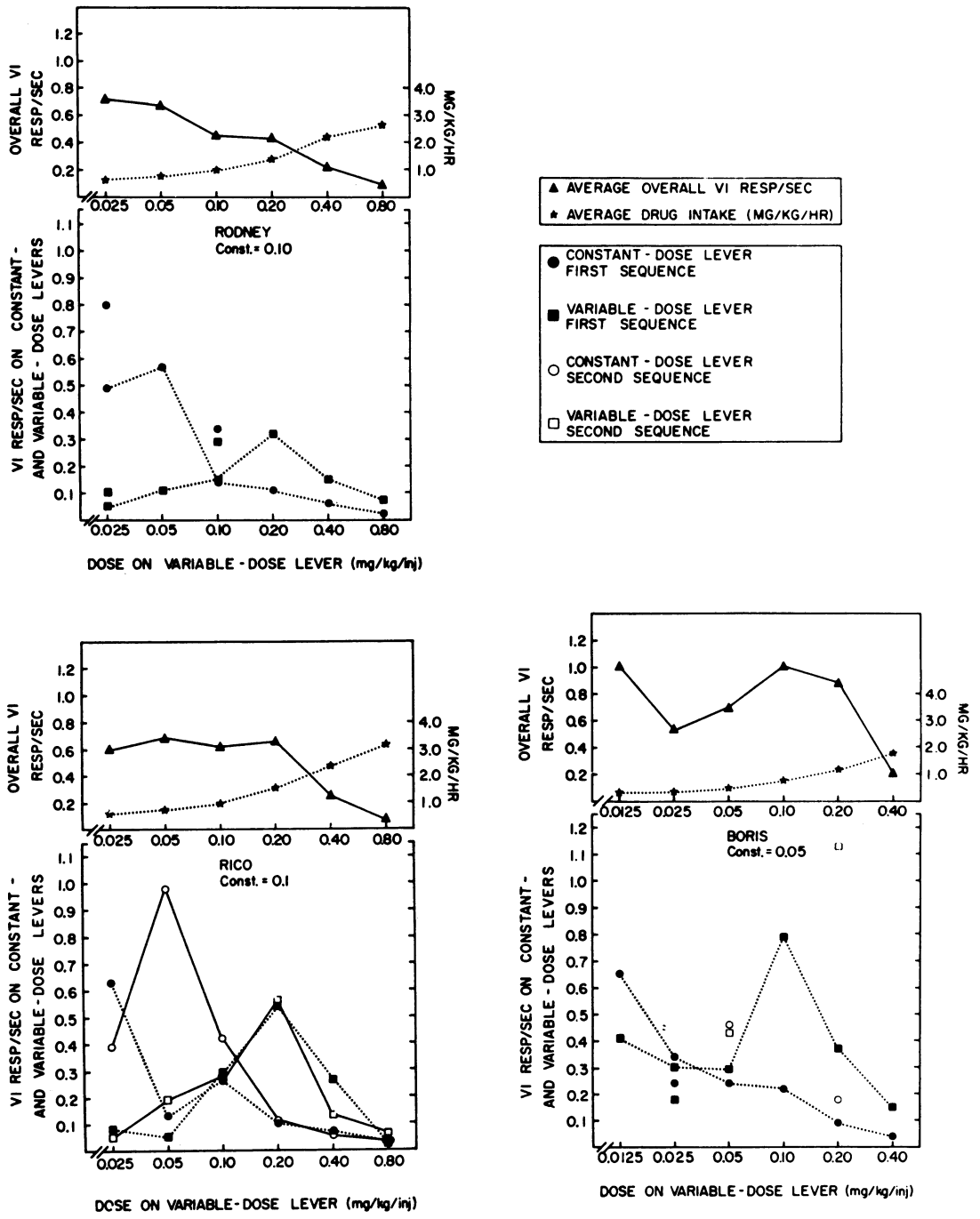

Fig. 3. Absolute variable-interval response rates (responses/sec) and hourly drug intake (mg/kg/hr) plotted against dose on the variable-dose lever. Doses are logarithmically spaced. The constant dose is indicated on each graph under the monkey's name. The bottom portion of each graph shows absolute variable-interval rates on the constant- and variable-dose levers; data are from the criterion sessions at each determination. With repeated determinations in a sequence, only the first is joined to the line. The top portion of each graph shows overall absolute variable-interval response rates and hourly drug intake for each dose comparison; data for each animal are averaged across determinations.

found in a study by Johanson and Schuster (1975). In their procedure, five responses on either of two levers would result in delivery of the cocaine dose associated with that lever. On each trial, only one dose could be obtained, since the first response on one lever inactivated the other lever for the remainder of the trial. Again, monkeys usually preferred the larger cocaine dose, preference in the Johanson and Schuster study being defined as the proportion of total injections.

On the other hand, under the present nonindependent procedure, preferences as extreme as those reported by Iglauer and Woods did not occur. Rather, over most of the dose range, the degree of preference is a function of the difference between the logarithms of the variable dose and the constant dose. The slope of the sigmoid curve relating relative response frequency to dose is greatest at doses adjacent to the point where the variable dose equals the constant dose (Figure 2). At either extreme of the variable-dose range, the slope decreases. Whereas in the lower portion of the curve the slope is always greater than zero, such is not the case in the upper portion of the curve. At these higher comparison doses (greater than 0.2 mg/kg/inj for Rico and Rodney; greater than 0.1 mg/kg/inj for Boris), preferences showed no consistent increases with dose.

This lack of monotonicity may reflect a real asymptote in the reinforcing efficacy of cocaine. However, there are two reasons for doubting such an interpretation of the data. First, some monkeys showed graded increases in preference over the same dose range in the independent concurrent variable-interval procedure of Iglauer and Woods. Second, the asymptote in relative response frequency occurred in Boris at a lower dose and with a lower constant dose than in the other two monkeys. Iglauer and Woods argued that exclusive preferences in their experiments resulted from an interaction between low rates of responding on the nonpreferred lever and the particular schedule parameters used. We suggest an analogous explanation for the asymptotic preferences in the present study.

Under nonindependent variable-interval schedules, a minimum number of responses is required on each lever in order to complete the session, because when a reinforcer becomes available on one lever it must be collected before the schedule can advance. It can be easily demonstrated that for the present study, the mathematical minimum is 30 responses per lever per session on the average. In practice, however, the minimum response requirement will be somewhat greater, since because of the COD, alternations of single responses between levers, as well as bursts of responding during the COD period, cannot result in delivery of an available reinforcer. To see the importance of this point, it is necessary only to consider a session in which just 200 responses are made. It is impossible in such a session for the monkey to exhibit a preference of 0.89, for example, since 30 responses would be required on one lever and 240 responses on the other. In fact, the greatest preference logically possible in this case is 0.85; given the foregoing discussion, it would probably be less in practice.

Precise evaluation of the practical minimum requirement was not possible with the present data-collection methods. However, the applicability of the argument may be assessed in the light of overall rates of responding (Figure 3). The theoretical minimum response requirement on each lever entails a minimum response-to-reinforcer ratio of two on each lever. When overall response rates are relatively high, the ratio of responses to reinforcers is relatively large. Therefore, even with a large proportion of responses occurring on the preferred lever, the minimum response to reinforcer ratio requirement on the nonpreferred lever may be satisfied. Consequently, a wide range of preferences is possible in the high-rate case. However, when the overall response rate is low, the ratio of responses to reinforcers is relatively small. Thus, a far smaller proportion of responses is labile, and the range of preferences possible is restricted by the schedule demands. Figure 3 shows that in the high-dose comparisons, all monkeys' rates of responding were usually extremely low and at these doses, preference was asymptotic (Figure 2; Table 1, Column 7).

Low response rates have been observed in a number of studies in which intravenous injection of cocaine has served as the reinforcer (*e.g.*, Dougherty and Pickens, 1973; Downs and Woods, 1974; Johanson and Schuster, 1975). The 5-min timeout used in the present study and in that of Iglauer and Woods (1974) introduced a fixed delay between cocaine de-

livery and the onset of the variable-interval component. A further, variable delay, the duration of which was determined by the monkey's behavior, was imposed by the requirement of a center-lever response to initiate the variable-interval component. The intent of these two delays was to minimize the influence of the preceding cocaine injection on variable-interval responding. At all but the highest comparison doses, these procedures appeared to be successful, since across monkeys overall variable-interval response rates were not systematically related to comparison dose over the lower portion of the dose range (upper sections of graphs in Figure 3). In addition, in this portion of the comparison-dose range, the latency to respond on the center lever appeared to be unrelated to the magnitude of the preceding injection.

However, after injections of the highest comparison doses, marked increases occurred in the latency to respond on the center lever. At the same time, in such high comparison-dose sessions, the variable-interval response rates were very low, as discussed above. Taken together, these observations suggest, first, that at most comparison doses, preference was not affected by cocaine's general response-disrupting properties. Second, the occurrence of much lower overall variable-interval response rates at higher comparison doses suggests that in these sessions, response-disrupting effects of cocaine persisted beyond the duration of the two delays (a finding also observed by Iglauer and Woods, 1974). An apparent consequence of these effects of cocaine was, as we have argued above, that preference showed no further increases as the comparison dose was increased beyond 0.2 (Rico and Rodney) or 0.1 mg/kg/injection (Boris).

In concurrent variable-interval procedures in which different frequencies of a given magnitude of reinforcement are available under each variable-interval schedule, a common finding is that the relative response frequency on each manipulandum approximately matches the relative amount of reinforcement obtained via each lever (Herrnstein, 1970). When identical variable-interval schedules are used, each delivering different reinforcer magnitudes, matching of relative response frequency and relative obtained reinforcer magnitude is less commonly found (*e.g.*, Fantino *et al.*, 1972; Todorov, 1973; Walker, Schnelle and Hurwitz, 1970). Using the latter type of procedure, Iglauer and Woods did observe matching, although the average deviation from matching was greater than usually reported in frequency-type concurrent variable-interval studies. Moreover, the matching observed by Iglauer and Woods was in a sense trivial, owing to the frequent occurrence of exclusive preferences. In the present study, relative response frequency approximately equalled relative reinforcer magnitude, as demonstrated by the distribution of data points along the diagonal of perfect matching in Figure 2. Deviations from matching were greater than those observed by Iglauer and Woods; however, these deviations were less than commonly reported in nonindependent concurrent variable-interval schedules (*e.g.*, Herbert, 1970; Menlove, Moffitt, and Shimp, 1973; Schneider, 1973; Walker and Hurwitz, 1971).

In conclusion, the major findings of the present study are that under a nonindependent concurrent variable-interval schedule of cocaine reinforcement, rhesus monkeys prefer the larger of two doses of cocaine, that the degree of preference is generally dependent on the magnitude of the comparison dose, and that preference roughly obeys the matching law. If relative response frequency is considered an index of reinforcer efficacy, then these findings suggest that the reinforcing efficacy of cocaine is a function of dose per injection. Although it is not entirely clear why at high-dose comparisons the relationship between relative response frequency and dose reached an asymptote, dose-related low rates of responding may account for this finding.

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