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THE ROLES OF STIMULUS CONTROL AND REINFORCEMENT FREQUENCY IN MODULATING THE BEHAVIORAL EFFECTS OF d-AMPHETAMINE IN THE RAT

DAVID C. REES, RONALD W. WOOD, AND VICTOR G. LATIES

UNIVERSITY OF ROCHESTER SCHOOL OF MEDICINE AND DENTISTRY

The behavioral effects of *d*-amphetamine have been shown to be modulated by stimulus control, with less impairment of performance occurring when control is great. When the fixed-consecutive-number schedule is used (on which at least a specified consecutive number of responses must be made on one operandum before a single response on another will produce a reinforcer), response rate tends to be invariant but reinforcement frequency is not. This study asks whether the differences in reinforcement frequency that usually accompany changes in stimulus control could themselves be responsible for the performance differences. Two versions of the fixed-consecutive-number schedule of reinforcement were combined into a multiple schedule within which stimulus control was varied but differences in reinforcement frequency were minimized by omitting some reinforcer deliveries during the component that usually had the higher reinforcement frequency. In one component, a compound discriminative stimulus was added with the eighth consecutive response on the first lever; a single response on the second lever was then reinforced. In the other component, no such stimulus was presented. With no added stimulus, large decreases occurred in the number of runs satisfying the minimum requirement for reinforcement at doses of drug that produced only minimal changes when an added stimulus controlled behavior. Thus, increased stimulus control diminishes the behavioral changes produced by *d*-amphetamine even when the possible contribution by baseline reinforcement rate is minimized.

Key words: stimulus control, reinforcement frequency, fixed-consecutive-number schedule, *d*-amphetamine, chained schedule, tandem schedule, lever press, rats

Behavior under the control of external discriminative stimuli is usually less sensitive to modification by the amphetamines than is behavior not under such control (see Laties, 1975, and Thompson, 1978, for reviews). Early demonstrations of this phenomenon did not control for the possible influence of differences in baseline response rates (e.g., Laties & Weiss, 1966; Thompson & Corr, 1974). One approach to equating those rates in drug studies of stimulus control has been to use the fixed-consecutive-number (FCN) schedule of reinforcement. On this schedule, a specified minimum number of consecutive responses must be made on one operandum before a single response on a second is reinforced. This schedule usually generates the high rates characteristic of low fixed-ratio schedules (Laties, 1972; Laties, Wood, & Rees, 1981; Szostak & Tombaugh, 1981; Wagman & Maxey, 1969; Wood, Rees, & Laties, 1983). These rates are not changed by adding a discriminative stimulus when the response requirement has been met on one operandum and reinforcement is available for a response on the other. Although these schedules minimize response-rate differences, they still per-

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mit differences in reinforcement rate between the two stimulus-control conditions, because the subject typically produces more reinforcers when a discriminative stimulus indicates reinforcer availability.

The present work examines whether stimulus control still modulates the changes produced by *d*-amphetamine on FCN performance when both reinforcement frequency and response rate are roughly equated.

METHOD

Subjects

Adult male Long-Evans rats were kept at 300 ± 20 g throughout the study. Four rats (10, 11, 12, 14) had prior exposure to *d*-amphetamine (Laties et al., 1981) and 2 were drug naive (15 and 16). The effects of *d*-amphetamine on initial and subsequent determinations were comparable. Rats 11, 12, and 14 were used for the main matching and yoking experiments. Rats 10, 11, 15, and 16 were used in two brief ancillary experiments. Rats 15 and 16 were not given drugs. Results also are presented for five additional rats at a single-dose level (1.7 mg/kg). Of these five rats, one (21) had prior exposure to toluene and two (67 and 69) had prior exposure to chlorpromazine; the remaining two (61 and 62) were naive. All prior drug or chemical exposures for all animals occurred at least 4 months before the initiation of these studies.

Apparatus

A Lehigh Valley Electronics rat chamber, with two Gerbrands levers mounted on the front wall with a white jewel light above each, was used for these experiments. White noise (76 dB) was always present. Sweetened condensed milk diluted with two parts water was used as the reinforcer; 0.1 ml was presented for 3 s. A force of approximately 0.26 N was required to move the right lever and record a response; 0.18 N was required for the left lever.

Schedule control and data collection were performed with a SuperSKED software system (Snapper, Kadden, & Inglis, 1982).

Procedure

A multiple schedule consisting of two types of the fixed-consecutive-number schedule of reinforcement was established for this experiment (Laties et al., 1981; Wood et al., 1983). The two versions differed in that one presented a discriminative-stimulus complex when a response requirement had been satisfied, whereas the other did not.

The rats were first trained to press the right lever with every response being reinforced. During this training, the houselight was off, and the light over the right lever was on. After the animals had been trained to press the right lever, the right-lever light was extinguished and the left-lever light was turned on. A single press on the left lever now extinquished the left-lever light and lit the right-lever light; in the presence of the right-lever light, a press on the right lever produced milk delivery. The houselight was lit during reinforcement. After this chain had been established, an 80 dB 2.9 kHz tone (SC628 Sonalert) was added so that the exteroceptive discriminative stimulus controlling the switch from left to right levers consisted of the offset of the left-lever light and the onset of the tone and right-lever light. The response requirement on the left lever was increased gradually over several sessions to the final value of eight or more consecutive responses. If fewer than eight responses had been made on the left lever, a response on the right lever reset the requirement. Each sequence of presses on the left lever before a right-lever press was designated as a "run." This is the fixed-consecutive-number schedule (Mechner, 1958), with the addition of external discriminative stimuli that come to control the switch from left to right lever. It can as easily be described as a chained schedule with the initial link consisting of the ratio requirement (with the resetting feature) and the terminal link consisting of a fixed-ratio 1 (Ferster & Skinner, 1957). This schedule will be abbreviated FCN-S^D.

After the rats met the minimum response requirement (8) on at least 90% of the runs, they were exposed to a multiple schedule. The houselight, which had been off except during reinforcer delivery during FCN-S^D, was used as the discriminative stimulus to denote the second component (FCN), which differed from

the first in that no external discriminative stimuli (both lever lights were off) were correlated with the completion of the response requirement on the left lever and thus with the availability of reinforcement for pressing the right lever. This component was equivalent to a tandem schedule. Hence, the animals responded on a multiple chained-tandem schedule of reinforcement (Ferster & Skinner, 1957).

Each session began with the FCN-S^D component, which consisted of 11 response runs. The first run was discarded in data analyses. Upon completion of the 11 runs, the FCN schedule was presented for 10 runs, after which FCN-S^D was again in force. The components alternated in this fashion until 50 runs on each had been completed, irrespective of whether they satisfied the criterion for reinforcement.

The criterion for stability of baseline performance was at least 12 successive sessions without systematic changes in response rates, switch times (time from the last press of a run to a press on the right lever), or the number of runs meeting the FCN requirement.

Minimization of Reinforcement Frequency Differences

Primary reinforcement-frequency differences were minimized between the components in two different ways. The first procedure *matched* the probability of milk delivery in FCN-S^D according to the mean proportion of reinforced runs in FCN that had been obtained during 30 preceding control sessions on the multiple schedule for that animal. These proportions were as follows: Rat 11: .50; Rat 12: .38; and Rat 14: .48. Therefore, the probabilities that they would be given food pellets upon satisfying the response requirement on the FCN-S^D schedule were .50, .38, and .48, respectively.

The second procedure *yoked* the FCN-S^D probability of reinforcement to that in the immediately preceding FCN component except for the first FCN-S^D component in a session, which was set equal to the mean probability from 30 baseline FCN sessions. For example, the probability was set equal to .4 if the rat had satisfied the minimum requirement on 4 of 10 runs during the immediately preceding FCN component. The efficacy of these procedures is shown in Table 1. About half of the runs were reinforced on FCN, and the matching and yoking procedures produced comparable figures for FCN-S^D. The means ± SD were roughly comparable between the matched components for Rats 11 and 12. Rat 14's FCN reinforcement frequency was somewhat higher than for FCN-S^D, making the conclusions yet more conservative. Reinforcement frequency was higher for Rat 14 in the yoked than in the matched FCN-S^D procedure.

After performance had stabilized on the unmatched multiple FCN FCN-S^D, a dose-response curve for *d*-amphetamine was determined (reported in Laties et al., 1981). The dose-response curve was then redetermined using the matching procedure (see *Drugs*, below). Subsequently, the behavioral effects of one dose (1.0 mg/kg) were redetermined on the original unmatched multiple schedule. Finally, the yoking procedure was instituted and drug effects were evaluated at a selected dose level for each subject. The procedures and dose levels are summarized in Table 2.

Drugs

d-Amphetamine sulfate (0.1 to 3.0 mg/kg; 1.0 ml/kg body weight) was injected intraperitoneally 10 min prior to each drug session. Drug days were Tuesday and Friday. Saline controls were performed on Thursday; noninjection control days were Monday and Wednesday. For Sequences I and II, doses were first administered in a descending, then an ascending, series. Duplicate determinations were made for the single-dose work in Sequences III and IV. During the redetermination with the unmatched procedure, Rat 12 was diagnosed as having murine pneumonia and was treated with tetracycline, an event with behavioral consequences discussed later.

Response Measures

Overall rate: the rate of responding during a whole session on the left lever, excluding the time occupied by food presentation.

Postreinforcement interval (PRI): the time be-

Table 1
Obtained FCN-S^D and FCN primary reinforcement (%) for both the matching and yoking procedures under saline and control conditions. Values are means ± 1 SD.

	Rat 11		*Rat 12*		*Rat 14*	
	FCN-S^D	*FCN*	*FCN-S^D*	*FCN*	*FCN-S^D*	*FCN*
Matched	50 ± 6.3 (n = 27)	55 ± 3.8	42 ± 7.0 (n = 34)	38 ± 5.1	35 ± 4.9 (n = 39)	48 ± 6.2
Yoked	57 ± 4.5 (n = 16)	58 ± 4.0	41 ± 2.5 (n = 10)	38 ± 2.3	53 ± 4.5 (n = 11)	48 ± 4.3

tween completion of the food cycle and initiation of responding on the left lever.

Switch time: the time between a right-lever response and the immediately prior left-lever response.

Running rate: the rate of left-lever responding, measured from the first to the last response on this lever in a run.

Runs ⩾ 8 (%): the percentage of runs long enough to meet the minimum requirements for reinforcement.

Conditional probability: this measure answers the question: Given a particular run length, how likely is it that the subject will switch to the reinforcement lever? This measure uses as a denominator for each run length the number of times that run length was reached or exceeded during a session, and uses as a numerator the incidence of the particular run length of interest (see Mechner, 1958). Probabilities were not calculated after the denominator diminished to fewer than 20 runs.

RESULTS

Matching Procedure

The top row of Figure 1 shows percentages of runs ⩾ 8, our primary measure of how the behavior conformed to the requirements of the FCN schedules. For all three rats almost all runs under control conditions met the minimum requirement under FCN-S^D. This performance was not greatly affected until the very highest dose of *d*-amphetamine for Rats 11 and 14 and not at all for Rat 12. Under FCN, the drug-induced decrements tended to be greater and to occur at lower doses. At 1.7 mg/kg, where the differential effects were most pronounced, the percentage of FCN-S^D runs that met the requirement for reinforcement remained at 80% or greater, whereas it fell to 20% or lower during the FCN.

Dose-related decreases occurred in both overall rate and running rate, with Rat 14 showing the smallest changes (Figure 1, second row). Unlike the finding with the runs ⩾ 8 measure, the decreases were proportionately similar for both components of the multiple schedule. Compare, for instance, the rate changes for both FCN-S^D and FCN at 1.7 mg/kg, a dose that produced marked differential effects on the runs ⩾ 8 measure.

Length of the postreinforcement interval decreased in a dose-related manner for both components of the multiple schedule with no consistent differential effect (Figure 1, third row).

Table 2
Summary of Procedures

Treatment Sequence	*Relation of FCN-S^D Primary Reinforcement Probability to FCN*	*Subjects*	*Dose (mg/kg) d-Amphetamine Sulfate*
I	unmatched*	11, 12, 14	0.1, 0.3, 0.56, 1.0, 1.7, 3.0
II	matched	11, 12, 14	0.1, 0.3, 0.56, 1.0, 1.7, 3.0
III	unmatched	11, 12, 14	1.0
IV	yoked	11	0.56
		12, 14	1.0

* From Laties et al., 1981

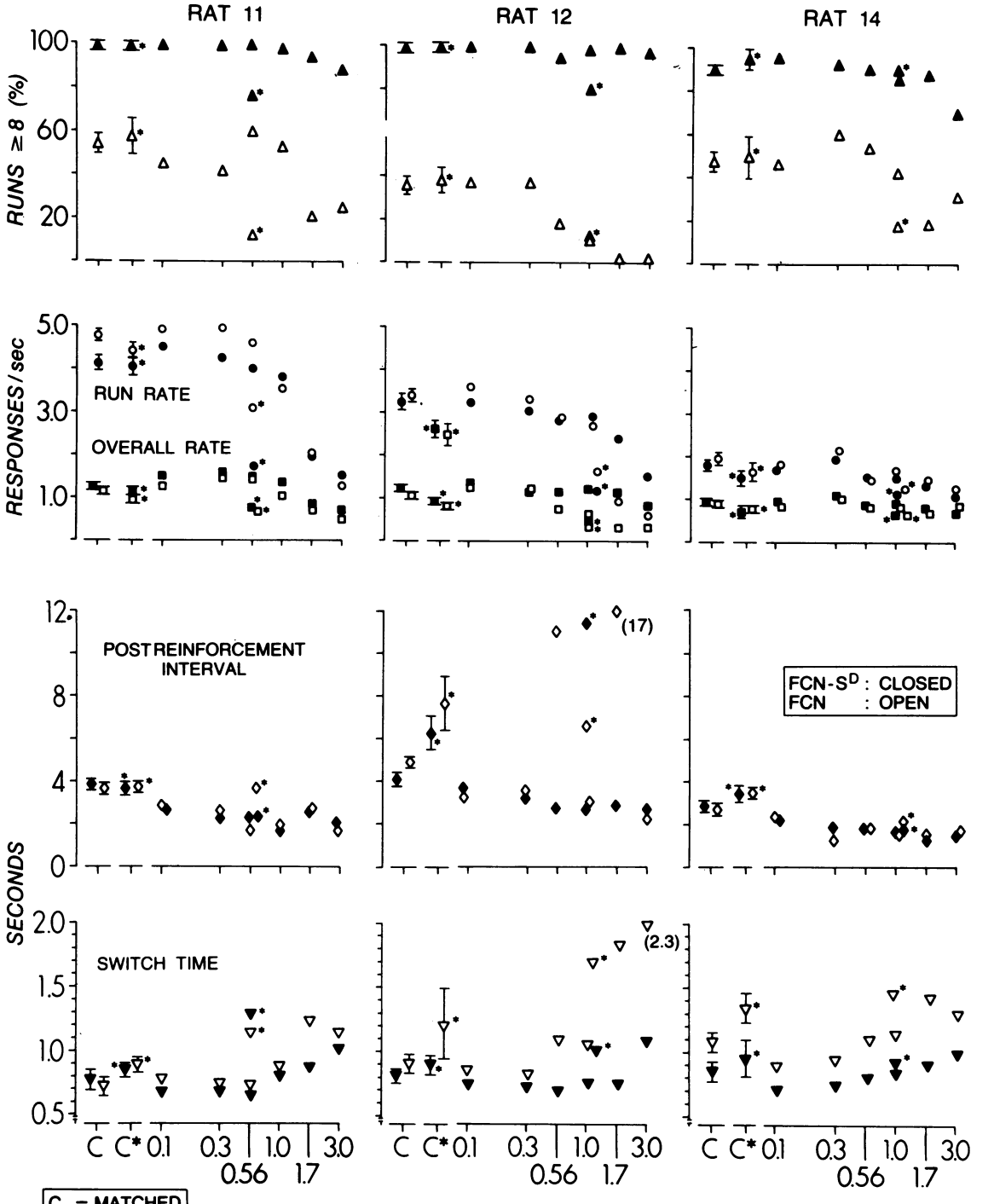

Fig. 1. Effects of *d*-amphetamine sulfate on different behavioral endpoints for both the matching and yoking procedures. Error bars are control 95% confidence intervals. All data presented are derived from the matching procedure, with the exception of those from the yoking procedure denoted by an asterisk. Drug points are means of two determinations. If fewer than five reinforcers were obtained, postreinforcement interval values are not presented.

Table 3

Summary of behavioral effects of 1.7 mg/kg *d*-amphetamine given to 5 additional rats under the matching procedure.

Rat	Multiple Schedule Component	Runs ≥ 8 (%) Control	Runs ≥ 8 (%) Drug	Overall Rate (Resp/s) Control	Overall Rate (Resp/s) Drug	Running Rate Resp/s) Control	Running Rate Resp/s) Drug	Postreinforcement Interval (s) Control	Postreinforcement Interval (s) Drug	Switch Time (s) Control	Switch Time (s) Drug
21 ($N = 3$)	FCN-S^D	97.9	88.0	0.70	0.65	1.37	1.54	5.20	5.91	1.68	1.67
	FCN	60.3	48.0	0.57	0.58	1.10	1.74	6.79	11.61	1.82	2.45
61 ($N = 10$)	FCN-S^D	99.6	96.0	1.44	0.25	3.44	1.77	2.78	2.68	0.94	0.81
	FCN	31.0	15.2	1.51	0.13	4.76	3.79	2.23	1.50	1.14	0.82
62 ($N = 10$)	FCN-S^D	87.6	40.0	1.39	0.94	3.92	1.28	3.34	1.55	1.39	1.50
	FCN	63.9	17.0	1.24	0.65	3.82	1.65	3.47	1.83	1.46	2.26
67 ($N = 10$)	FCN-S^D	91.0	94.0	1.11	1.08	1.62	1.47	2.76	1.43	0.83	0.79
	FCN	21.6	4.8	1.16	0.54	2.82	1.58	2.67	1.68	1.02	1.62
69 ($N = 10$)	FCN-S^D	94.4	85.0	1.04	0.20	1.86	1.54	3.12	2.70	0.92	0.93
	FCN	50.4	33.0	0.94	0.15	1.80	1.67	3.38	2.77	1.10	1.00
Mean	FCN-S^D	94.1	80.6	1.14	0.62	2.44	1.52	3.45	2.85	1.15	1.14
(*SD*)		(4.91)	(23.13)	(0.30)	(0.40)	(1.15)	(0.18)	(1.01)	(1.81)	(0.37)	(0.41)
	FCN	45.4	23.6	1.08	0.41	2.86	1.88	3.71	3.88	1.31	1.63
		(18.64)	(16.96)	(0.35)	(0.25)	(1.48)	(1.15)	(1.80)	(2.17)	(0.33)	(0.73)

Switch time did show differential effects with somewhat greater drug-induced lengthening when the FCN schedule was in force, especially for Rat 12 (Figure 1, bottom row). For each rat a dose that produced large differential changes in runs ≥ 8 (1.7 mg/kg) also differentially increased switch times outside the range of control values. In addition, there was some indication that switch time was decreased by the lower doses of *d*-amphetamine under both schedules.

Results from five additional animals support these overall findings (Table 3). These rats were given only doses of 1.7 mg/kg *d*-amphetamine. Rat 21 was tested on three occasions; the others were tested 10 times. Runs ≥ 8 for FCN-S^D decreased a mean of 14% compared with a 48% decrease for FCN; these differential effects were independent of changes in the temporal structure of behavior. Although such changes occurred, they were comparable for the two schedules.

Yoking Procedure

Figure 1 also presents data generated with the procedure that yoked reinforcement frequency in the two components (denoted by asterisks). Only a single dose was used with each rat. In general, results with this procedure support those from the matching procedure. Performance under FCN-S^D on runs ≥ 8 was less impaired than was FCN performance. Rats 11 and 12 showed signs of dis-

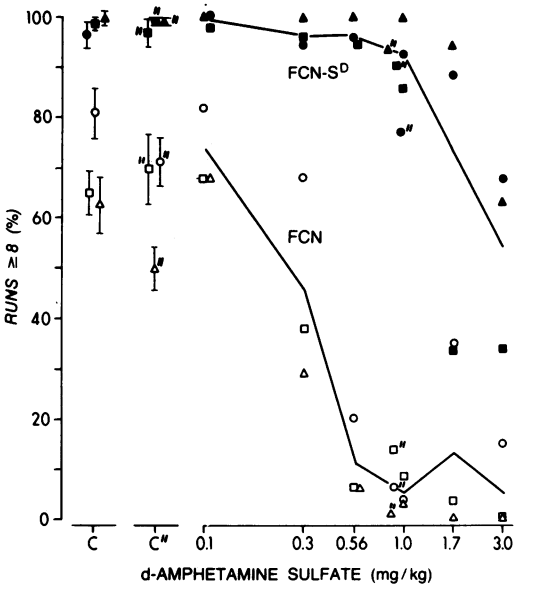

Fig. 2. Effects of *d*-amphetamine sulfate on the percentage of runs that were long enough to be reinforced for both the unmatched procedure (Laties et al., 1981) and its redetermination (″). Each rat is represented by a unique symbol (filled for FCN-S^D and unfilled for FCN); squares (Rat 11), triangles (Rat 12), circles (Rat 14). Mean values are connected by the solid lines. The vertical lines above C and C″ denote the 95% control confidence intervals.

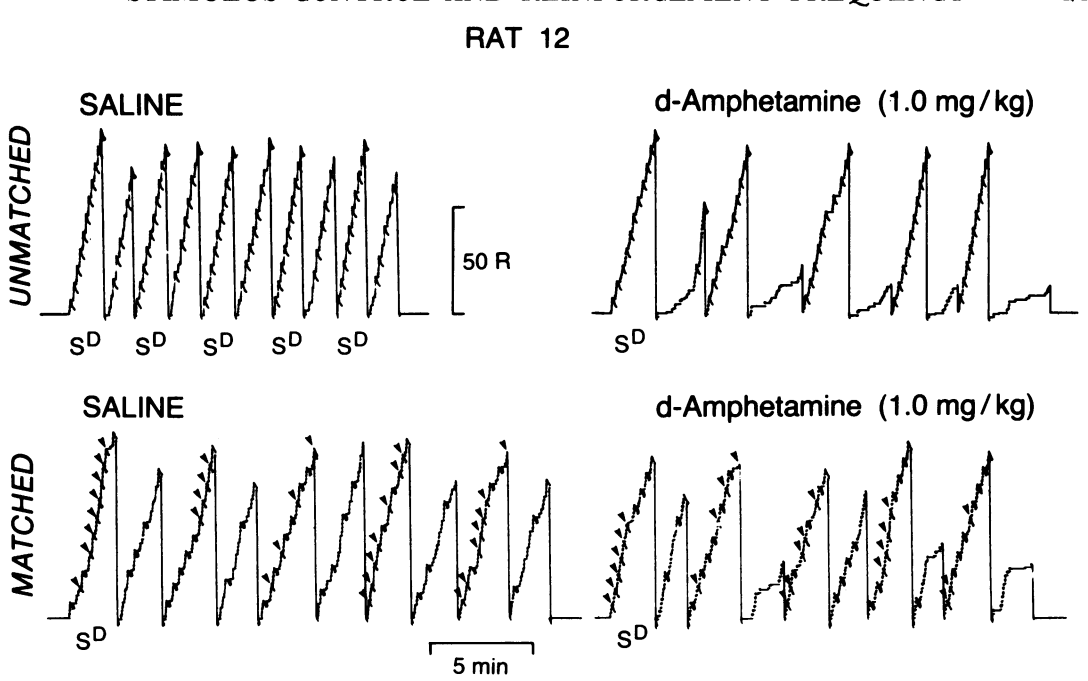

Fig. 3. Cumulative records of performance on the multiple FCN FCN-S^D schedule of reinforcement for the unmatched and matching treatment procedures. Responses on the left lever moved the pen upward. Right-lever responses following eight or more left-lever responses are indicated by oblique pips. Arrowheads indicate run lengths that met the minimum response requirement but were not reinforced with milk. The pen reset to the baseline with completion of the 10th run in each component of the schedule.

ruption in the FCN-S^D component at lower doses when food reinforcement was yoked than when it was matched to the FCN level. However, note that, with yoking, an additional decrement in reinforcement frequency was produced because any frequency reduction in the FCN component led to a further reduction in FCN-S^D. Such a drug-induced reduction in reinforcement frequency was perhaps severe enough to itself have effects on the control exerted by either the schedule itself or the discriminative stimuli (cf. Figure 4). There were many instances that a rat received *no* food during an FCN-S^D component, even though the minimum response requirement had been met, because the drug had reduced reinforcers to zero during the immediately preceding FCN component. The arrowheads on the bottom record in Figure 4 indicate such omissions of food.

All rats showed decreased overall rates. There were idiosyncratic differences observed among animals in running rate, switch time, and PRI measurements. For example, Rat 14 had similar changes on left-lever running rates in both components, whereas FCN-S^D running rates were not impaired for Rats 11 and 12. Generally, the rats were somewhat more sensitive to the drug when on the yoked than when on the matched procedures.

We previously showed (Laties et al., 1981) that *d*-amphetamine had differential effects on the two schedules when reinforcement density was *not* equated; all the unmarked symbols in Figure 2 represent data from that work for Rats 11, 12, and 14 of the present study. To ensure the validity of comparisons between those results and the present results with matching, redeterminations of effects of 1.0 mg/kg (see Table 2) were made without matching. Both the original data and the redeterminations show clear evidence of a greater drug effect during the FCN condition.

Cumulative records of Rat 12's responding for both matching (Figure 3) and yoking (Figure 4) procedures demonstrate clear and immediate differential effects of 1.0 mg/kg *d*-amphetamine with both procedures.

Rat 12 was given tetracycline for murine pneumonia during the redetermination of the

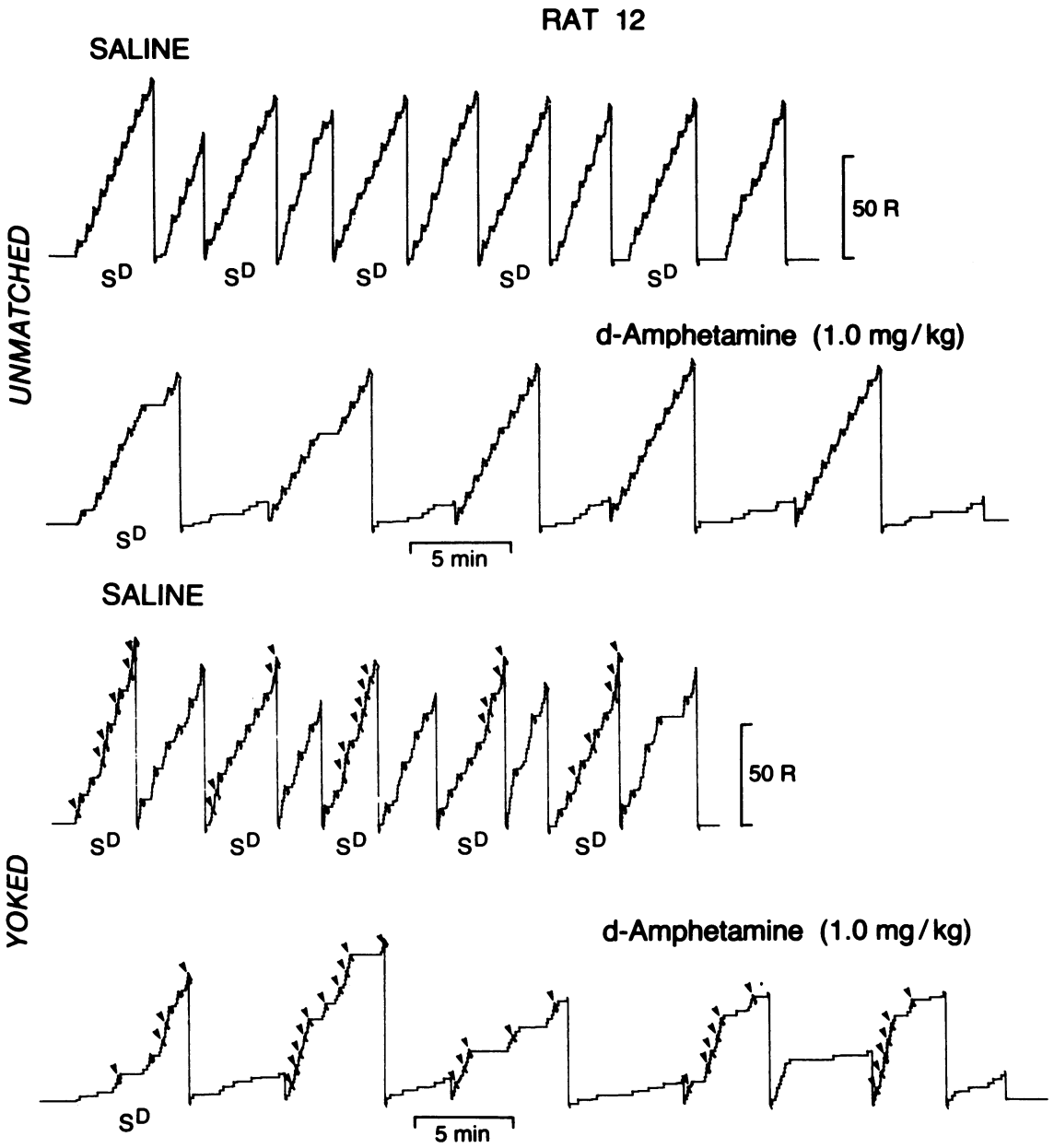

Fig. 4. Cumulative records of performance on the multiple FCN FCN-S^D schedule of reinforcement under the unmatched and yoking procedures for Rat 12 during a bout with pneumonia. Responses on the left lever moved the pen upward. Completions of runs satisfying the minimum response requirement are indicated by the oblique pips. Arrowheads indicate run lengths that met the minimum response requirement but were not reinforced with milk. The pen reset to the baseline with completion of the 10th run in each component of the schedule.

unmatched condition (Figure 4, upper records). The pneumonia was accompanied by a large decrease in control response rate. Despite this baseline rate change, the differential drug effect remained similar to that seen earlier (Figure 3, upper records). This accidental finding testifies to the robustness of the basic stimulus control/drug interaction.

Conditional probabilities of switching during the conditions in which reinforcement

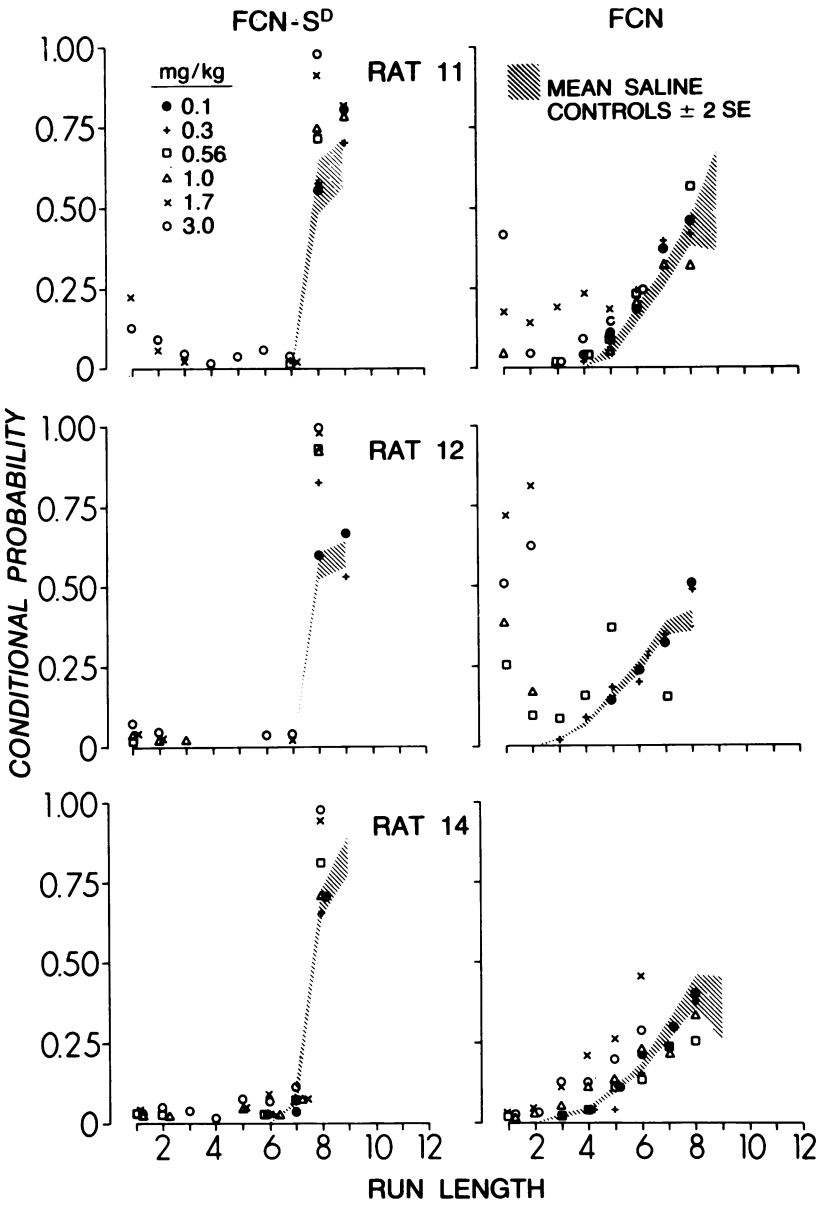

Fig. 5. Conditional probabilities for Rats 11, 12, and 14 under the matching procedure. The ordinate gives the probability that the rat will switch to the reinforcement lever after a run of the length given on the abscissa. Probabilities lower than .01 have not been plotted, nor have points based upon fewer than 20 runs. Shaded areas represent ± 2 SE for the control sessions, and are based upon 27 sessions (Rat 11), 34 sessions (Rat 12), or 39 sessions (Rat 14).

rate was matched are given in Figure 5. With FCN this increase occurred gradually; the shaded areas give the control performances (Figure 5, right). With FCN-S^D, the increase was abrupt, hardly any switches occurring with fewer than eight left-lever responses. For both components and for all rats, the probability of prematurely switching to the right lever increased with increasing dose of *d*-amphetamine. However, the number of doses after which this effect occurred and the magnitude of the effect were both greater under the FCN condition. The probability of switching after exactly eight responses was

markedly increased by *d*-amphetamine when the discriminative stimulus appeared with that response (FCN-S^D: Figure 5, left), whereas switching after that number was not affected in the absence of the added stimulus (FCN: Figure 5, right).

Subsequent Ancillary Experiments

Additional observations were undertaken immediately to clarify certain aspects of the results.

(1) The matching and yoking experiments described above minimized differences in reinforcement frequency between the two versions of the schedule by reducing the probability of food presentation following completion of the left-lever response requirement in the FCN-S^D component on the basis of performance in the FCN. In the first ancillary experiment, the probability of reinforcement in the FCN component was made much greater than that in FCN-S^D by reducing the run-length requirement to four. (The requirement remained at eight in the FCN-S^D component.) This led to more comparable percentages of runs meeting the minimum number in the two components (Table 4). In addition, because the matching procedure maintained the FCN-S^D reinforcement probability at .5 under control conditions, the obtained frequencies of reinforcement in the FCN-S^D component were only about half those obtained in the FCN component. Nevertheless, in the face of both biasing factors, *d*-amphetamine continued to affect FCN more than FCN-S^D performance. Rat 10 showed only an 8% decrease in percentage of runs ≥ 8 in the FCN-S^{D}component but a 43% decrease in runs ≥ 4 in the FCN component. Rat 11 showed a 50% decrease in the FCN-S^D component but a 91% decrease in FCN. The behavior under strong discriminative stimulus control continued to show the smaller drug effect.

(2) Higher doses of *d*-amphetamine can impair FCN-S^D performance more when a multiple FCN FCN-S^D schedule is used than when the schedules are studied separately (Laties et al., 1981). If these changes were due to impairment in discrimination of the components of the multiple schedule, manipulation of this control might itself lead to drug-like behavioral effects (Dews, 1958). The houselight was on during FCN and off during FCN-S^D. Other stimuli correlated with the FCN-S^D component were the white jewel light above the left lever (which was lit until the rat made its eighth response), the white jewel light above the right lever (which was dark until the eighth response on the left lever but then came on and remained lit until the rat depressed the right lever), and the tone that accompanied onset of the right light. Our rats appeared to orient towards the left-lever light, suggesting that it might be the most important controlling stimulus for the FCN-SeD component. Therefore, an attempt was made to vary the difference between components by manipulating the presence of the houselight and the left-lever

Table 4

Control and Drug Data for the Multiple FCN8-S^D FCN4 Schedule

	Control					*1.7 mg/kg* d-*amphetamine*				
	FCN8-S^D			*FCN4*		*FCN8-S^D*			*FCN4*	
Rat No.	*Runs $\geq$ 8 (%)*	*Reinf. Frequency (%)*	*Running Rate (resp/s)*	*Runs $\geq$ 4 (%)*	*Running Rate (resp/s)*	*Runs $\geq$ 8 (%)*	*Reinf. Frequency (%)*	*Running Rate (resp/s)*	*Runs $\geq$ 4 (%)*	*Running Rate (resp/s)*
10	97 ± 2.8 (N = 14)[a]	46 ± 6.8	2.4 ± 0.5	94 ± 4.0	3.0 ± 0.8	89 ± 1.9 (N = 3)	45 ± 16.4	0.75 ± 0.6	53.6 ± 12.1	0.77 ± 0.5
11	94 ± 13.2 (N = 17)[b]	48 ± 1.1	2.2 ± 0.3	79 ± 12.0	1.5 ± 0.5	46 ± 26.8 (N = 3)	25 ± 15.5	0.8 ± 0.2	7.2 ± 1.8	0.7 ± 0.2

Values represent mean ± 1 SD

N equals number of sessions

[a]6 sessions in a row plus 8 days interspersed among drug days

[b]6 sessions in a row plus 11 days interspersed among drug days

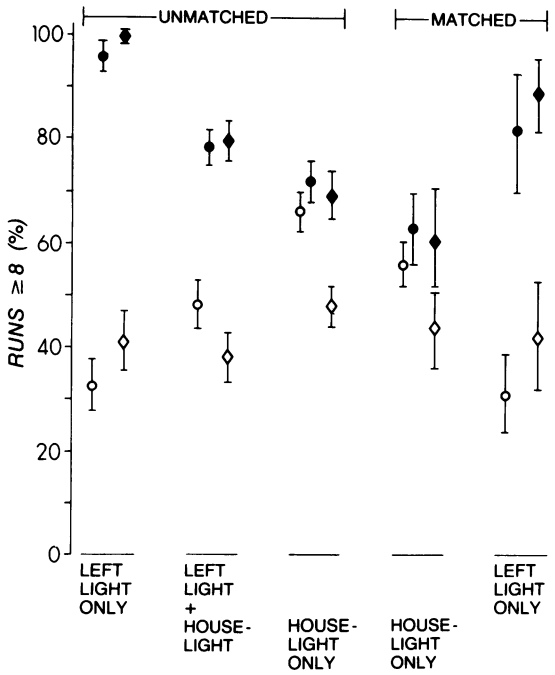

Fig. 6. Effects of altering control by the left-lever light on the percentage of runs that were long enough to be reinforced, by shifting the schedule from a multiple FCN FCN-S^D to a mixed FCN FCN-S^D schedule of reinforcement. Values represent means ± 95% confidence interval for FCN-S^D (filled) and FCN (unfilled); Rat 15 (circles), Rat 16 (diamonds). The numbers of sessions for each condition, from left to right, were 13, 30, 27, 16, and 10, respectively. Means are given for all the sessions under each treatment. Trends were sometimes present during prolonged exposure to a new condition but are of no importance for the present discussion.

light. The right light and the tone continued to function as usual. During the initial experiments, the matching procedure was not in effect.

Under control conditions—that is, on multiple FCN FCN-S^D as described above—the animals displayed near perfect performance in FCN-S^D and met the minimum requirement about 40% of the time in FCN (Figure 6, left column; because only the left-lever light and houselight were changed during these observations, only their state is shown at the bottom of the figure). The houselight's presence during FCN or absence during FCN-S^D formally denoted the multiple schedule components. Adding the houselight during FCN-S^D thus could be thought of as changing from a multiple to a mixed schedule. The second column of Figure 6 shows that FCN-S^D performance was degraded about 20% by this procedure. However, the left-lever light, which was on during each run in the FCN-S^D component, effectively served as a discriminative stimulus indicating the presence of that component. Removal of this light made the performances on the two components more similar—nearly indistinguishable in the case of Rat 15 (Figure 6, third column). Matching primary reinforcement frequency between components (by setting the probability of milk reinforcement to .5 for meeting the minimum run-length requirement while on FCN-S^D) tended to decrease run lengths further and to increase the variability (Figure 6, fourth column). Reinstatement of the left-lever light and removal of the houselight restored differential performance (Figure 6, right column). The obviously better discrimination between FCN and FCN-S^D components that can be seen in the far left and right columns shows that the effectiveness of the right-lever light and tone, which served as part of the discriminative-stimulus complex during the FCN-S^D component, was dependent upon the presence of a distinct multiple-schedule stimulus, the houselight or the left-lever light. The latter effectively served as a multiple-schedule stimulus even though not present throughout the entire component. By decreasing this control with a behavioral manipulation, it was possible to mimic the FCN-S^D performance degradation following high doses of *d*-amphetamine when FCN-S^D appears in a multiple schedule (Laties et al., 1981). It is possible that high doses of *d*-amphetamine selectively impair the control exerted by multiple-schedule stimuli, rather than impairing discriminative stimulus control within the FCN-S^D component itself.

DISCUSSION

Our main conclusion is that increased stimulus control continues to diminish the behavioral changes produced by *d*-amphetamine on the fixed-consecutive-number schedule even when the possible contribution of

baseline reinforcement rate is minimized. This finding is congruent with the fact that reinforcement frequency does not seem to be a very powerful variable in determining drug action when initial response rates have been equated and when changes in response rates are the subject of inquiry. For instance, Lucki and DeLong (1983) showed that *d*-amphetamine (0.25 to 4.0 mg/kg) affected equally the response rates of rats on random-ratio schedules (RR 20 and RR 50) with equal control response rates but with almost a threefold difference in control reinforcement rates.

Nevertheless, reinforcement rate may have played a minor role in the present work. The greater sensitivity to drug that was observed with yoking than with matching (Figures 1 and 4) may have stemmed from the near abolition by *d*-amphetamine of reinforcers delivered during the FCN component, and the consequent precipitous drop in food deliveries during the FCN-S^D portion of the multiple schedule because of the yoking. A minimum reinforcement frequency is undoubtedly required to maintain the integrity of control by the schedule of reinforcement itself; when all reinforcement is abolished, the schedule-controlled behavior should reflect the change to extinction.

Matching baseline reinforcement rates did not affect the way *d*-amphetamine enhanced the probability of a switch to the reinforcement lever if certain discriminative stimuli were presented (and others omitted) when the response requirement was completed (Figure 5, left column). Such an increase in probability, which may reflect enhancement of either the discriminative or the conditioned reinforcing properties of these stimuli (Blough, 1957; Robbins, Watson, Gaskin, & Ennis, 1983), closely resembles the results obtained previously with these three rats when no attempt was made to match reinforcements (see Figure 6 in Laties et al., 1981).

It is interesting to note that some doses of drug both enhanced switching at run length eight and increased the frequency of short run lengths. This was true also in the earlier study with these rats (Laties et al., 1981).

This experiment did not explore different gradations of stimulus control other than those created by manipulating the presence of several visual discriminative stimuli. The influence of more subtle changes in stimulus control has been studied by varying the physical intensity of an external discriminative stimulus (Katz, 1983). When Katz did this, *d*-amphetamine, in doses ranging from 0.1 to 5.6 mg/kg, exerted minimal effects even when control had been degraded considerably by reducing the intensity of the controlling stimulus. The measure of stimulus control, A', was reduced from about .95 to about .7, where 1 represented perfect control and .5 represented zero control. The behavior under control in Katz's experiment was choice of key color. Two of the other drugs studied, pentobarbital and promazine, degraded the performance more when stimulus control was relatively low, demonstrating that the absence of an amphetamine effect was not due to a general lack of sensitivity of the behavior. It may be that variation in stimulus control produced by changing the intensity of an external stimulus (here, the houselight) simply does not influence amphetamine's effects if a minimum stimulus intensity is exceeded.

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