JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR 1983, 39, 465-478 NUMBER 3 (MAY)

TEMPORAL CONTROL IN A COMPLEX ENVIRONMENT: AN ANALYSIS OF SCHEDULE-RELATED BEHAVIOR

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Three experiments conducted in an automated ten-compartment chamber recorded collateral activities of rats reinforced for lever pressing on differential-reinforcement-of-low-rate schedules. In Experiment 1, the rate of lever pressing increased when stimulus support for collateral activities was removed, thus confirming earlier findings. However, there were no temporal or sequential patterns of collateral activities that predicted operant responding. In Experiment 2, the rate of lever pressing increased only if (a) access to all stimulus support for collateral activities was simultaneously prevented, and (b) the rat was forced to remain in the presence of the lever and food tray. The availability of any of the stimuli related to collateral activity was sufficient to keep lever-pressing rates from increasing. Experiment 3 examined collateral activities under a signaled differential-reinforcement-of-low-rate schedule. Preventing access to stimuli supporting collateral activities had little effect on stable lever pressing when the signal was maintained. When the signal was removed, collateral activities continued, but lever-pressing rates increased in three of the four rats and rates of food presentation declined in all rats. Hypotheses that collateral activities have (a) a timekeeping or discriminative function, or (b) directly inhibit operant responding were not supported. The results suggest that collateral activities may facilitate operant responding by simply removing the subject from the presence of reinforcement-related stimuli.

Key words: DRL, fixed-time, collateral, lever press, competition, concurrent, rats

Experimental manipulation of collateral activities affects the rate of operant responding under the control of differential-reinforcement-of-low-rate (DRL) schedules. Preventing the occurrence of established collateral activities increases the rate of operant responding, and providing stimuli for the occurrence of collateral activities generally reduces the rate of operant responding.

There are four hypotheses regarding the inverse relationship between collateral activities and operant responding. First, collateral activities serve as the timekeeping mechanism and become discriminative for the operant response (e.g., Laties, Weiss, Clark, & Reynolds, 1965; Wilson & Keller, 1953). Second, collateral activities directly inhibit the operant response (e.g., Schwartz & Williams, 1971; Staddon, 1977). Third, collateral activities develop as a byproduct of inhibited operant responding (Richelle & Lejeune, 1980). Fourth, collateral activities remove the subject from the proximity of stimuli controlling operant responding (McGown, Spencer, & Neetz, 1977). The present experiments used an automated ten-compartment chamber to examine these hypotheses.

Laties et al. (1965) and Laties, Weiss, and Weiss (1969) prevented established collateral activities in rats and obtained increased rates of operant responding. Laties et al. (1965, 1969) argued that collateral activities function as discriminative stimuli for the occurrence of the operant. This discriminative-stimulus hypothesis is a version of a response-chaining hypotheses that proposes that a relatively invariant chain of conditioned responses intervenes between the operant responses (Wilson & Keller, 1953).

Glazer and Singh (1971) trained rats to lever press on a DRL schedule under conditions of physical restraint or no restraint, and then reversed the conditions. The restraint condition resulted in higher rates of lever pressing and

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Part of this research was supported by a grant from the University of Wisconsin—Eau Claire. The authors thank Blaine Peden for his many comments on early versions of this manuscript. Requests for reprints should be sent to Kenneth McIntire, Department of Psychology, University of Wisconsin—Eau Claire, Eau Claire, Wisconsin 54701.

Glazer and Singh argued that the response-produced-discriminative-stimulus hypothesis could not account for the results.

Frank and Staddon (1974) and Richardson and Loughead (1974) performed experiments using pigeons and a restraint condition like that of Glazer and Singh (1971) and obtained comparable results. However, Frank and Staddon (1974) and Staddon (1977) hypothesized that collateral activities compete for expression with, and inhibit, operant responses. A similar response-inhibition hypothesis was proposed by Schwartz and Williams (1971), who observed pigeons in a discrete-trials procedure that required the birds not to peck for six sec after the key was illuminated. More reinforcers were obtained if collateral key pecking occurred on a second key that had no programmed consequences. Schwartz and Williams concluded that collateral activities are essential to the "response constraining contingency" of DRL schedules and that rats perform better than pigeons on DRL schedules because they have a broader range of activities in which to engage during the interreinforcement interval. This response-inhibition hypothesis was extended by Hemmes, Eckerman, and Rubinsky (1979), who found that the rate of collateral key pecking by pigeons was directly related to the rate of obtained reinforcers on a DRL schedule.

Richelle and Lejeune (1980) reviewed the literature on short-term temporal control and concluded that collateral activities are not part of the timekeeping mechanism, nor do they inhibit operant responding. They proposed that operant responding is directly under the control of the reinforcement schedule. Collateral activities develop as compensatory by-products when operant responding is inhibited by the temporal properties of a reinforcement schedule (p. 199).

In contrast to the above hypotheses, a hypothesis that does not assume direct interactions among response classes was presented by McGown et al. (1977), who recorded the relation between wood chewing and lever pressing in rats. When wood was removed from the chambers of the rats trained with wood present, the rate of lever pressing increased. McGown et al. (1977) suggested that wood chewing facilitated temporal discrimination only because it kept the rats away from the manipulandum early in training.

The present analysis of the temporal and sequential properties of collateral activities and operant responding was conducted to evaluate the different hypotheses.

EXPERIMENT 1

The purposes of Experiment 1 were to perform a detailed temporal and sequential analysis of collateral activities while operant lever pressing was under the control of a DRL schedule and to demonstrate a relationship between collateral activities and operant lever pressing under the conditions of the present experiment.

METHOD

Subjects

Four male albino rats, derived from Holtzman stock at the University of Wisconsin—Eau Claire, were food deprived and maintained at 80% of their free-feeding body weights for two weeks prior to the start of the experiment until the completion of the experiment. The rats were between 120 and 150 days of age at the beginning of the experiment and were trained in the light phase while maintained on a normal light-dark cycle.

Apparatus

Figure 1 shows the Plexiglas experimental chamber and lists the contents of each of the compartments. Each compartment was separated from the immediately adjacent compartments by vertical walls. The central compartment, or passageway, was circumscribed by 10 inner walls. Each of the inner walls contained a 6.35 cm by 6.35 cm square hole about 1.27 cm above the floors that provided the only entrance to a compartment. The floors of all the compartments were covered with 1.27-cm mesh hardware cloth except for Compartment 2 (C_2), which was solid Plexiglas, and Compartment 4 (C_4), which was a grid of brass rods.

Each of the floors was hinged to the outside wall of the experimental chamber to allow free vertical movement of the central end of each floor. Each floor was counterbalanced and required approximately .8 N to close a switch mounted under the floor. The experimental chamber was located on the floor of a 1.5 m by 2.5 m cubicle, which was part of a suite of five rooms in which normal laboratory activities were usually in progress.

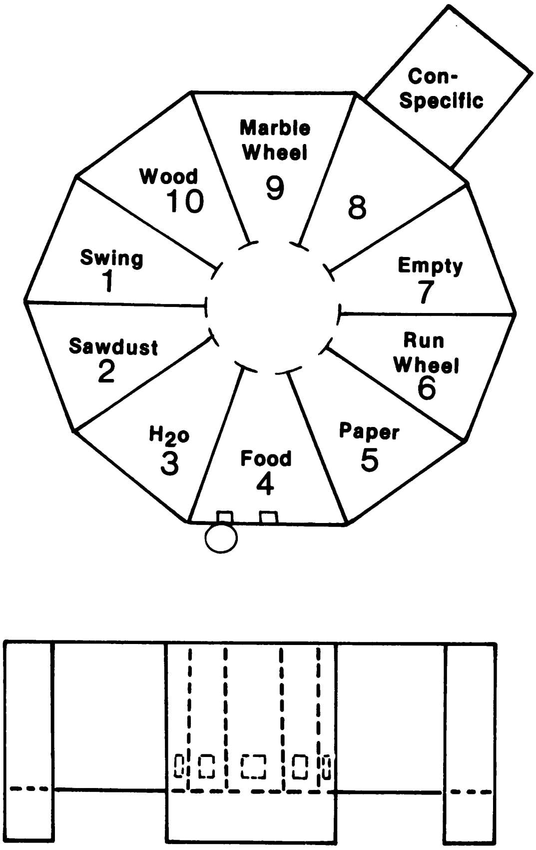

Fig. 1. Top (upper) and side (lower) views of the experimental chamber. Each compartment (C_j) contained different stimuli. C_1, swing. C_2, wood shavings about 2.0 cm deep. C_3, water bottle mounted to the outside wall. C_4, Lehigh Valley lever mounted to the outside wall about 5.0 cm above the floor. Food trough, 2.5 cm by 2.5 cm, adjacent to the lever about 2.5 cm above the floor. C_5, shredded paper about 5.0 cm deep. C_6, running wheel, 25.4 cm diameter. C_7, empty. C_8, conspecific in a cage adjacent to the compartment. C_9, spoked drum containing marbles that clanked when rotated. C_{10}, piece of wood.

Programming and recording were performed by Coulbourn solid state logic located in an adjoining room. In addition, the rat's location in the chamber was monitored by an Esterline-Angus 20-pen event recorder.

Procedure

Sessions were between 55 and 65 min in length and were conducted five days per week. In Session 1, lever pressing was shaped with the rats locked in C_4. Beginning with Session 2, all rats were allowed unrestricted access to all compartments (the Open condition), and the reinforcement schedule was changed so that 45-mg Noyes food pellets were presented only if 28 sec elapsed between consecutive lever presses (DRL 28-sec). The DRL 28-sec schedule of reinforcement remained in effect for the duration of the experiment. Two rats (17 and 20) received 30 sessions in the Open condition, and two rats (5 and 44) received 36 sessions in the Open condition. Lever-pressing rates stabilized after 20 sessions, but more sessions were completed because the characteristics of performance in the chamber were unknown, and it was uncertain whether the rates would decline further. After training in the Open condition, all rats were locked in C_4 (the Closed condition). Closed sessions continued until the mean lever-pressing rate for each rat was equal to or less than the mean rate of lever pressing for the five Open sessions preceding the beginning of the Closed condition. When mean rates of lever pressing in the Closed condition had returned to previous Open condition levels, the Open condition was reintroduced for five sessions. The order of conditions was thus Open, Closed, Open.

RESULTS AND DISCUSSION

Operant Responding

Figure 2 shows the mean rates of lever pressing and mean rates of food presentation for each rat during the entire Closed condition and the five days of the Open condition immediately preceding and following the Closed condition.

From the first Closed session all rats increased lever pressing rates, which decreased food presentation rates. It took between 43 (Rat 17) and 56 (Rat 44) Closed sessions for mean lever-pressing rates to return to the levels obtained previously during the Open condition. In the final five Open-condition sessions, lever-pressing rates were lower than any previous sessions and food-presentation rates were equivalent to those prior to the Closed condition.

Figure 3 shows the mean interresponse-time (IRT) distributions for lever pressing for five sessions before and after the Open-Closed and Closed-Open transitions for each rat. The IRT distributions before the introduction of the Closed condition show a large proportion of short (0 to 4 sec) IRTs and very long (over 32 sec) IRTs. Introducing the Closed condition

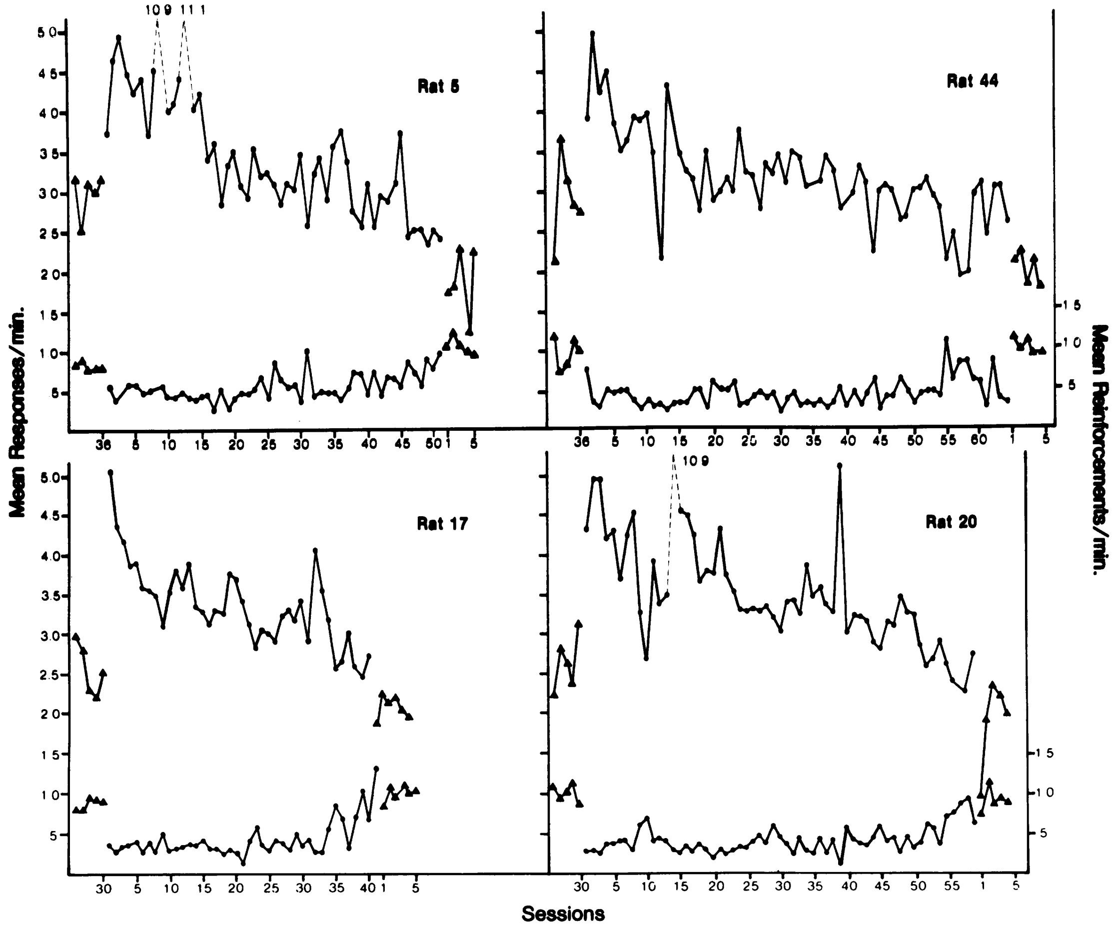

Fig. 2. Mean rates of lever pressing and food presentation for each rat in Experiment 1. All Closed sessions are presented along with the five Open sessions preceding and following the Closed sessions. Lever-pressing rates are higher than food-presentation rates on all graphs.

reduced the frequency of IRTs over 32 sec and shifted the distribution toward shorter (less than 28 sec) IRTs. By the end of the Closed-condition sessions, the 0 to 4-sec IRTs diminished and the proportion of lever presses in the 28 to 32-sec IRT bin increased. The reinstatement of the Open condition resulted in a return of IRTs over 32 sec.

Collateral Activities—Sequential Properties

All data on collateral activities were selected for presentation prior to being analyzed. Figures 4 to 7 contain two consecutive daily transition matrices (C_{jk}) for each rat. The data were selected to represent sequential properties during early, middle, and final stages of training.

Though some compartments, e.g., C_3, were entered more frequently than others, the pattern of collateral activities differed among rats, and rats differed from session to session. Were the location immediately preceding entry to C_4 discriminative for entry to C_4, it would be expected that the C_{j4} transition would always be from the same C_j and entry to C_j would be timed by entering from some other area, C_i, with C_{ij4} chained back to the previous exit from C_4. Figures 4 to 7 show that transitions among the areas were probabilistic in nature. That is, given that a rat was in C_4, transitions were made to all other C_j. And given that a rat was in C_j, the highest probability transition was to C_4. The probabilistic patterning of transitions is similar to the data reported by Staddon and Simmelhag (1971) and Staddon and Ayres (1975) using fixed-time reinforcement schedules. The pattern of transitions is what would be expected if there was

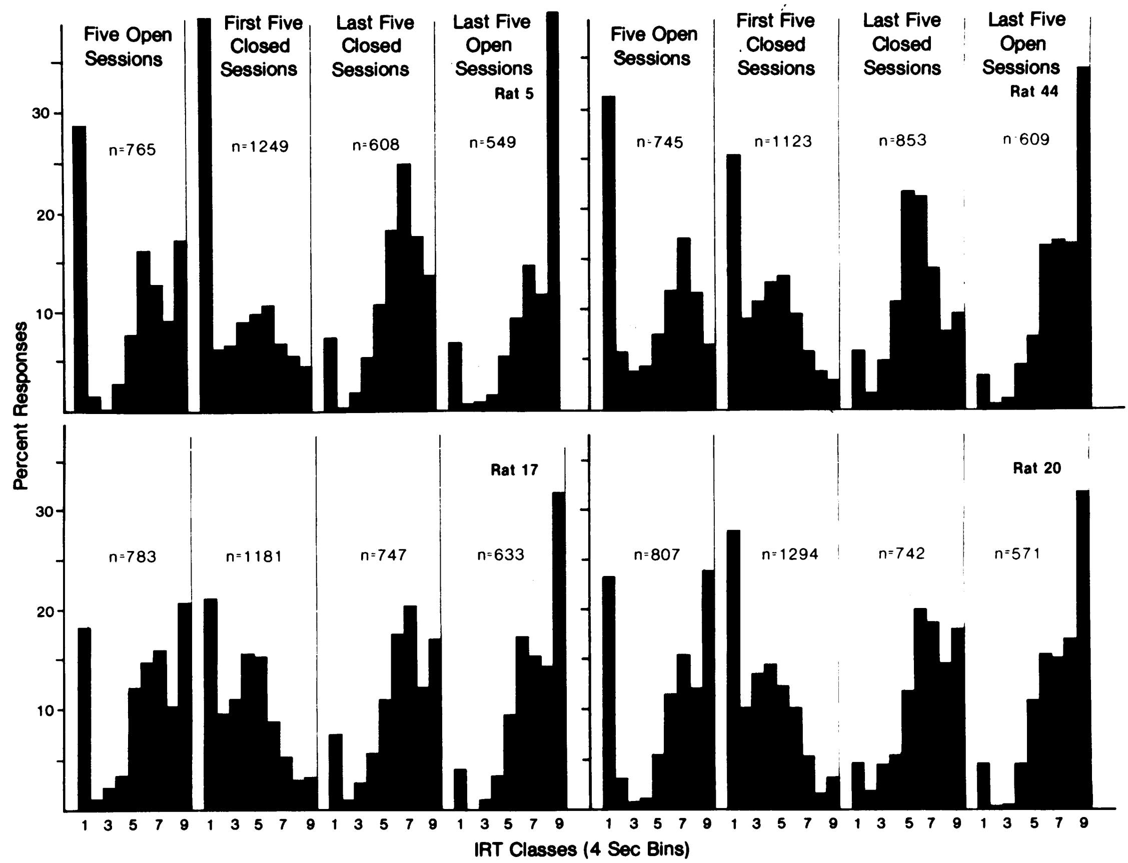

Fig. 3. IRT distributions for lever pressing for each rat in Experiment 1 for the final five Open sessions before the Closed sessions, the first and last five Closed sessions, and the last five Open sessions. Each distribution represents the results of five sessions. The total number of lever presses from which each distribution was calculated is represented above that distribution.

simply an overall compartment preference for each rat.

Transition sequences for one rat were summed across four sessions to determine whether any apparent pattern of activity would emerge with an increased number of observations. The data in Figure 8 are consistent with the data for the same rat in Figure 5, showing mainly an overall compartment preference with a low frequency of transitions among the least-frequented compartments.

	Session 14												Session 15										
	C_k												C_k										
C_j	1	2	3	4	5	6	7	8	9	10	F		1	2	3	4	5	6	7	8	9	10	F
1				1.0							4	1				1.0							10
2				.50	.50						2	2				.75	.25						4
3				.79	.16			.03		.03	38	3				.92	.08						25
4	.04	.01	.19		.33	08	.09	.17	.02	.06	97	4	.04	.04	.15		.57	.04	.05	.07	.02	.02	81
5		.02	.28	.70							31	5	.14	.02	.16	.67							49
6			.33	.55			.11				40	6				.67			.33				3
7			.22	.67	.11						9	7			.20	.80							5
8			.18	.76							17	8			.50	.50							6
9				1.0							2	9			.50	.50							2
10			.14	.57	.29						7	10				1.0							2

Fig. 4. C_{jk} transition probabilities for Rat 5, Sessions 14 and 15. Numbers in the F column are the total frequencies from which the probabilities were calculated. Deviations from unity represent rounding error.

	Session 29												Session 30										
	C_k												C_k										
C_j	1	2	3	4	5	6	7	8	9	10	F		1	2	3	4	5	6	7	8	9	10	F
1		.20		.60				.20			5	1				.50	.25			.25			4
2				1.0							3	2				1.0							4
3				.95				.02		.02	42	3				.91					.02	.07	46
4	.04	.02	.30		.10	.03	.15	.27	.03	.06	116	4	.01	.03	.46		.06	.01	.10	.12	.01	.19	93
5				.94				.06			16	5			.11	.89							9
6				.80				.20			5	6				1.0							2
7				1.0							16	7				.73				.09			11
8			.08	.89						.03	37	8	.13			.87							17
9			.33		.33	.33					3	9				.75						.25	4
10			.33	.22	.22			.22			9	10	.14	.04	.08	.42	.13	.04	.04	.13	.08		24

Fig. 5. C_{jk} transition probabilities for Rat 17, Sessions 29 and 30. Data are presented as in Figure 4.

		Session 28												Session 29										
		C_k												C_k										
		1	2	3	4	5	6	7	8	9	10	F		1	2	3	4	5	6	7	8	9	10	F
C_j	1				1.0							3	1				1.0							5
	2			.5	.5							2	2				.75					.25		4
	3				.91	.04			.02		.02	47	3	.02			.96	.02						44
	4		.01	.36		.26		.07	.28		.01	94	4	.04	.02	.35		.22	.03	.13	17	.01	.04	112
	5				1.0							28	5		.04	.07	.90							29
	6												6			.5	.5							4
	7	.29		.43	.14	.14						7	7		.07	.14	.71	.07						15
	8	.04	.04	.25	.64	.04						28	8			.11	.83	.06						18
	9												9			.33	.67							3
	10				1.0							2	10				.20	.20	.20	.20	.20			5

Fig. 6. C_{jk} transition probabilities for Rat 20, Sessions 28 and 29. Data are presented as in Figure 4.

A three-state analysis was performed to test for higher order sequencing constraints. Figure 9 shows the results of a three-state analysis for one rat for one session. Because of the large number of responses recorded, only the three most probable were analyzed, with the remainder pooled into a fourth category, C_0.

The C_{ijk} transition probabilities in Figure 9 indicated that sequencing constraints were highly unlikely. The transition from C_j to C_k was relatively unaffected by the preceding C_i. However, if the food compartment was visited more than two activities ago, it may have had a higher probability of being entered than when it was first in a sequence of three. But the frequencies are low.

Despite the failure to observe transition sequencing constraints, an analysis was performed to determine if reinforced lever presses were preceded by a different compartment than nonreinforced lever presses. Table 1 shows the probability of making a reinforced lever press after entering C_4 from each of the other compartments for one session for each rat.

Though the probability of emitting a reinforced lever press was not equal for each C_{j4} transition, there was little to indicate any strong effects of response sequencing. The cells containing zeros in the table were infrequently entered, and the zeros probably reflect sampling error.

		Session 11												Session 12										
		C_k												C_k										
		1	2	3	4	5	6	7	8	9	10	F		1	2	3	4	5	6	7	8	9	10	F
C_j	1				.82					.09	.09	11	1				.86				.14			7
	2				.83						.17	6	2				.50		.17				.33	6
	3	.03			.77	.06			.03	.03	.09	43	3	.06			.88					.06		80
	4	.04	.06	.13		.02	.02	.04	.15	.02	.53	111	4	.08	.08	.24		.03	.01	.07	.22	.09	18	67
	5			.08	.39						.54	13	5				1.0							4
	6			.11	.67			.22				9	6				.50	.50						2
	7				1.0							13	7	.20			.80							5
	8				.96						.04	27	8			.13	.81	.06						16
	9			.10	.70		.10				.10	10	9				1.0							7
	10	.07		.22	.22	.11	.09	.12	.09	.08		76	10				1.0							14

Fig. 7. C_{jk} transition probabilities for Rat 44, Sessions 11 and 12. Data are presented as in Figure 4.

		C_k									
			2	3	4	5	6	7	8	9	10	F
C_j	1		.05	.10	.68	.05			.10			19
	2				.86	.07					.07	14
	3				.93	.005		.005	.02	.005	.04	180
	4	.03	.02	.35		.09	.02	.13	.23	.02	.13	424
	5			.09	.88						.03	57
	6				.82			.09	.09			11
	7	.05	.02		.78				.03	.02	.12	64
	8	.02	.01	.04	.86	.02	.01				.04	109
	9		.08	.08	.58	.08	.08				.08	12
	10	.03	.02	.18	.26	.13	.02	.07	.26	.02		94

Fig. 8. C_{jk} transition probabilities for Rat 17 calculated from the total Sessions 28, 29, 30, and 31. Numbers in the F column are the total C_{jk} frequencies from which the probabilities were calculated. Deviations from unity represent rounding error.

Collateral Activities—Temporal Properties

Figures 10 and 11 show the probabilities of Rats 17 and 44's location in the chamber for 80 sec past the presentation of food at 4-sec intervals. For reasons of clarity, only the four most-probable compartments are shown in the

Table 1

The probability of a C_{j4} transition followed by a reinforced lever press for one session for each rat. Empty cells indicate that particular C_{j4} transition did not occur during the session. Numbers in parentheses are the frequencies of each C_j transition. Equivalent probabilities for C_{44} transition (—) were not recoverable from the data.

	Rat	*5*	*17*	*20*	*44*
	Session	*20*	*36*	*30*	*20*
C_j	1	.25 (4)	.0 (5)		.50 (4)
	2	.0 (1)	.50 (2)	.50 (2)	.0 (1)
	3	.52 (33)	.67 (18)	.65 (34)	.59 (32)
	4	—	—	—	—
	5	.20 (5)	.75 (12)	.60 (5)	.0 (1)
	6	.40 (5)			.50 (4)
	7	.61 (18)	.33 (3)		.67 (9)
	8	.37 (19)	.25 (4)	.67 (3)	.56 (16)
	9	.40 (5)	.0 (1)		.0 (3)
	10	.50 (4)	.25 (8)	.0 (2)	.75 (12)

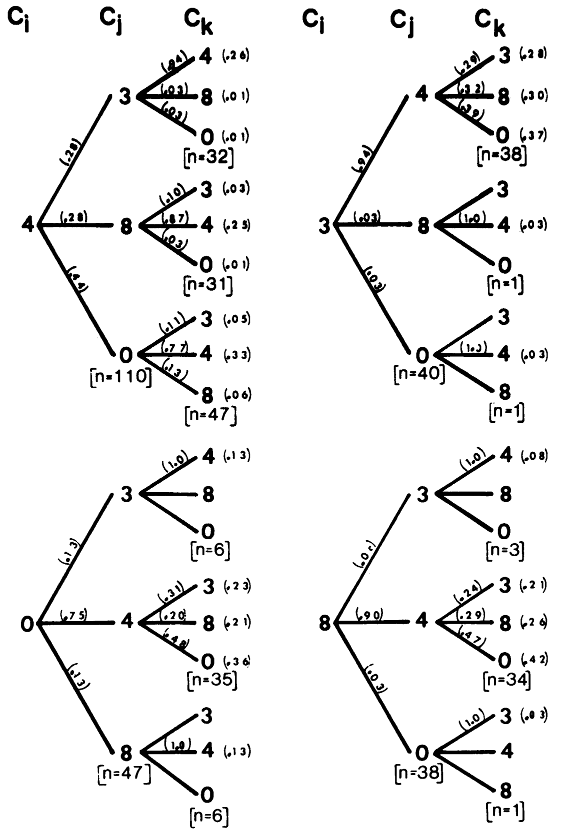

Fig. 9. C_{jk} transition probabilities for Rat 17, Session 29. C_3, C_4, & C_8 are water, food, and conspecific, respectively. C_0 is the summation of the remaining seven compartments. Unlabeled transitions all had a probability of 0.0. Probabilities not summing to 1.0 represent rounding error.

figures. The results are variable between rats and between sessions, and few generalizations can be made. Both rats showed an initial decrease in the probability of being in the food compartment followed by a small increase as the postreinforcement interval approached 28 sec. Aside from the inverse relationship between feeding and drinking, there was little evidence to support a hypothesis that the temporal distribution of collateral activities was functionally related to lever pressing except in the trivial sense that lever presses could not occur unless the rats were in C_4.

Conclusions

Experiment 1 resulted in six conclusions. First, blocking the occurrence of established collateral activities increased the rates of operant lever pressing, thus confirming and extending the findings of Glazer and Singh (1971), Laties et al. (1965, 1969), and Frank and Staddon (1974).

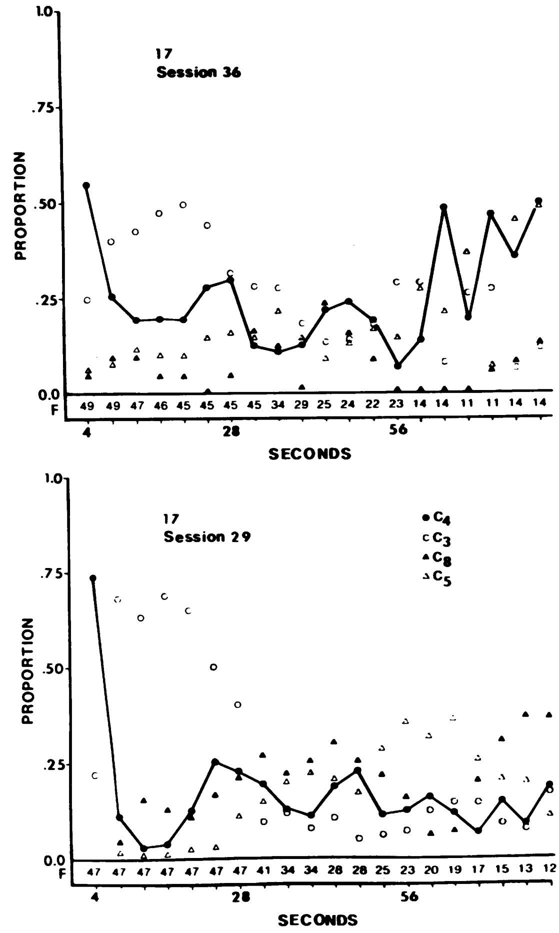

Fig. 10. The interreinforcement distribution of compartment location for Rat 17, Sessions 29 and 36. Location was sampled at 4-sec intervals after the presentation of food. Numbers in the F row along the abscissa are the total number of observations made at each 4-sec interval. Data points represent the proportion of the total number of observations that the subject was located in each compartment. Inequalities in the F row during the first 32 sec past food presentation resulted from the rat being in the central compartment, which was not considered for purposes of data analysis.

Second, the increased rates of lever pressing in the Closed condition declined to Open-condition levels only after extended training and resulted in lever-pressing IRT distributions different from the IRT distributions obtained in the Open condition.

Third, there was little evidence for sequencing constraints in either the C_{jk} or C_{ijk} transitions, and response sequencing was prob-

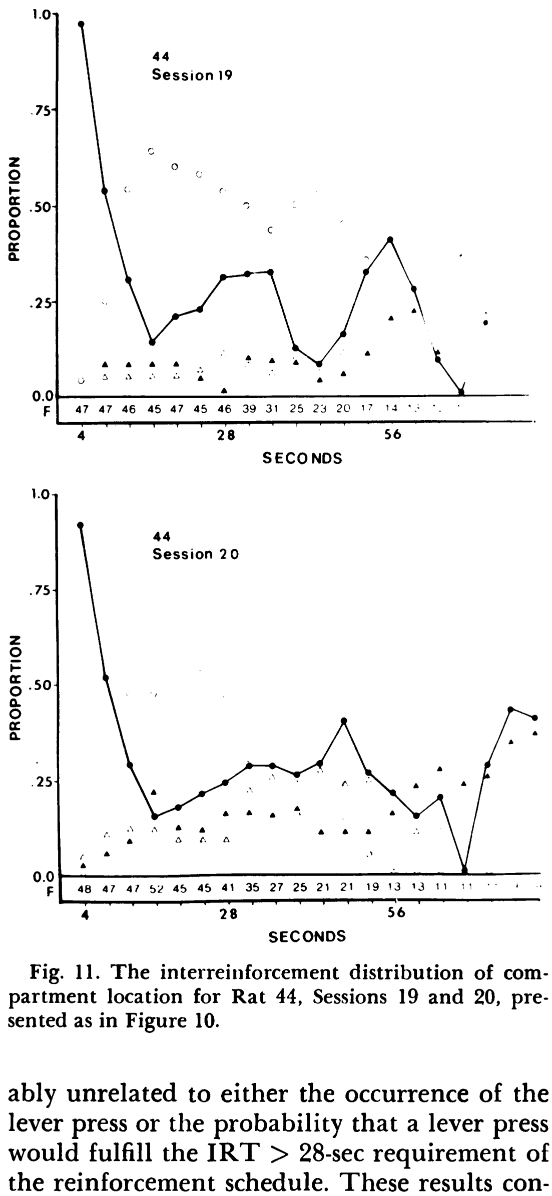

Fig. 11. The interreinforcement distribution of compartment location for Rat 44, Sessions 19 and 20, presented as in Figure 10.

ably unrelated to either the occurrence of the lever press or the probability that a lever press would fulfill the IRT > 28-sec requirement of the reinforcement schedule. These results confirm and extend the findings of Hemmes et al. (1979) and Smith and Clark (1975) and are consistent with the observations of Staddon (1972) and Staddon and Ayres (1975) using fixed-time schedules.

Fourth, the temporal distribution of location during the interreinforcement interval revealed no evidence of patterning that could account for the temporal patterning of C_4 entry. In contrast to Staddon and Simmelhag (1971) and Staddon and Ayres (1975), the pattern of behavior across time in the present experiment did not fall neatly into interim and terminal categories.

Fifth, the pattern of behavior emerging from Figures 9, 10, and 11 is that the rats left the food compartment soon after reinforcement and showed an increase in the probability of reentry as time approached 28 sec. In contrast to Laties et al. (1969), none of our rats remained in the food compartment during the interreinforcement interval. The difference in results is probably because Laties et al. (1969) used an empty alley attached to an operant chamber.

Finally, the present experiment confounded activity and distance from the lever, and chamber size is related to performance with DRL schedules (Skuban & Richardson, 1975). Although Experiment 2 will address this issue, one observation during the present experiment indicates that the location of the activities was relatively unimportant. During an early Closed session, the lever-pressing rate of Rat 5 suddenly dropped. After about 15 min we looked into the experimental room and found the rat chewing on a small piece of tape attached to the top of the food compartment. The tape had been placed there prior to the start of the experiment but was not chewed on previously. The tape was removed and lever-pressing rates immediately increased.

EXPERIMENT 2

In the Closed condition of Experiment 1 stimulus support for all of the recorded collateral activities was removed simultaneously. The increased rates of lever pressing may have resulted from either (a) the removal of the opportunity to engage in only one or some small number of the collateral activities, or (b) simply the reduced size of the chamber (Skuban & Richardson, 1975). In Experiment 2 collateral activities were removed either one, three, eight, or nine at a time. If the results of Experiment 1 were caused by eliminating only one or two of the collateral activities (e.g., drinking), this should be detected in Experiment 2. If the results of Experiment 1 were a function of reducing chamber size, there should be an inverse relation between the number of compartments eliminated and the number of reinforcers obtained.

METHOD

Subjects

Three naive albino rats were maintained as in Experiment 1.

Apparatus

Same as in Experiment 1.

Procedure

After an initial session of lever-press shaping in the food compartment, the reinforcement schedule was changed to DRL 28-sec and remained so until the end of the experiment. As the initial amount of exposure to the Open condition in Experiment 1 was not required for stable operant performance, sessions in Experiment 2 were one-half hour in length, five days per week. During Condition 1, Sessions 1 to 38, each rat had unrestricted access to all compartments in the experimental chamber and the amount of time spent in each compartment was recorded. During Condition 2, Sessions 39 to 47, the three most preferred compartments for each rat (not including the food compartment) were blocked off one at a time, three sessions each, in an unsystematic order. Preference was determined by the amount of time spent in each compartment. During Condition 3, Sessions 48 to 51, all three of the compartments blocked in Condition 2 were blocked at the same time. In Condition 4, Sessions 52 to 60, eight of the compartments were blocked at once, and unrestricted access was allowed only into the food compartment and one other compartment. The unrestricted compartment was different in each session, and the order of blocking the compartments was unsystematic. In Condition 5, Sessions 61 to 65, each rat was locked into the food compartment as in Experiment 1. In Condition 6, Sessions 66 to 70, an aluminum divider was placed across the food compartment about 20 cm from and parallel to the wall containing the lever, thus restricting the rats to the immediate proximity of the lever and food tray. Condition 7 was a reinstatement of Condition 1, for the final five sessions.

RESULTS AND DISCUSSION

Collateral Activities

Table 2

The proportion of total session time spent in each C_j for each rat during the last five Open sessions. All sessions were 30 minutes in duration.

	C_j									
Subject #	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
66	.017	.014	.188	.303	.080	.047	.055	.039	.231	.012
67	.073	.015	.313	.432	.025	.026	.036	.025	.041	.013
68	.117	.006	.339	.384	.021	.017	.018	.016	.023	.057

Table 2 shows the proportion of the total time during Sessions 34 to 38 (Open sessions) that was spent by each rat in each compartment. The data in Table 2 are consistent with the compartment-transition probabilities for Experiment 1, which revealed compartment preferences for each rat with C_3, drinking, among the most preferred. Table 2 also indicates that the three most preferred compartments accounted for between 74 and 83% of the time spent outside of C_4.

Operant Responding

Figure 12 shows the overall mean and range of the mean lever presses per minute for the sessions in each experimental condition for each rat. Two of the three rats (66 and 68) showed discernible increases in lever-pressing rates only when they were maintained in the food compartment (Condition 6 for Rat 6 and Conditions 5 and 6 for Rat 68). Rat 67 generally increased lever-pressing rates from Condition 1 through Condition 6 and returned to Condition 1 levels in Condition 7. This rat emitted short IRT bursts in Conditions 2 to 4, which had no effect on the overall rate of reinforcement. This is clearly shown in Figure 13, which shows the mean and the range of

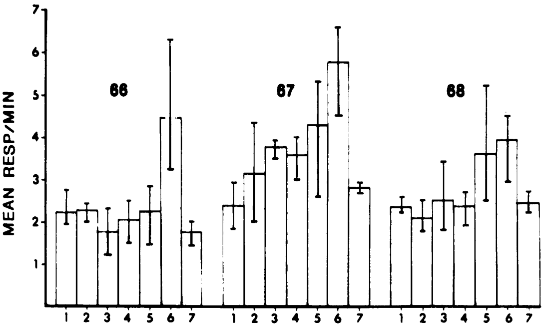

Fig. 12. Mean lever presses per min for each rat in each experimental condition of Experiment 2. Brackets represent the range of session means in each condition. The results of Condition 1 are for the last five Condition 1 sessions. The results of all other conditions include each session in each condition. Conditions 1 and 7 were unrestricted access to all compartments. In Conditions 2, 3, and 4, the number of blocked compartments were one, three, and eight, respectively. Condition 5 blocked the rats in the food compartment and Condition 6 reduced the size of the food compartment.

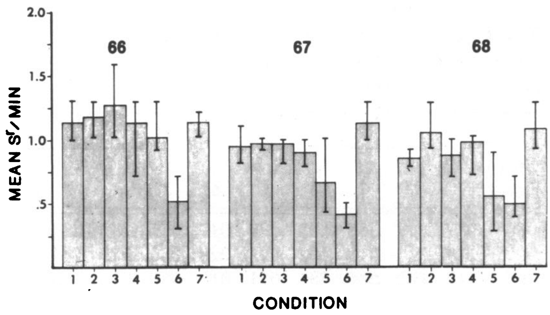

Fig. 13. Mean food presentations per min for each rat in each experimental condition of Experiment 2. Brackets represent the range of session means in each condition. The results of Condition 1 are for the last five Condition 1 sessions. The results of all other conditions include each session in each condition. Conditions are presented as in Figure 12.

the mean food presentations per minute for all sessions in each condition for each rat. The rate of food presentation for Rat 67 remained stable through Condition 4 in spite of increased rates of lever pressing, with reduced rates of food presentation only in Conditions 5 and 6. Rats 66 and 68 obtained reduced food-presentation rates consistent with the increased response rates in Conditions 5 and 6. Rates of lever pressing were highest and rates of reinforcement were lowest for all rats in Condition 6.

Conclusions

The results of Experiment 2 were consistent with the conclusions of Experiment 1. There was little to support a contention that the timing of the operant was dependent upon the pattern, sequencing, or temporal distribution of the preceding activities. These results are also consistent with those of Hemmes and Rubinsky (1982), who observed wheel running, chewing, and drinking in rats that were lever pressing on a DRL schedule. Wheel running, the most frequent activity, was prevented and two of the three rats showed no increase in lever-pressing rates.

In contrast to the results of Skuban and Richardson (1975), chamber size was unrelated to the obtained rate of reinforcement until the rats were blocked in the food compartment in Conditions 5 and 6. The difference in results is probably a function of the availability of alternative stimuli in the compartments and/or the ability to leave the food compartment in the present study.

Experiment 2 may also have implications for the study of concurrent operants. The experimental chamber can be construed as concurrently providing reinforcement for 10 different response classes with a changeover delay equal to the travel time between compartments. The time spent among the compartments may be conceptualized as representing the relative rate or amount of reinforcement in each of the compartments (Baum & Rachlin, 1969). Experiment 2 systematically removed the availability of reinforcement for activities except lever pressing. Time spent lever pressing did not increase in two of the three rats until all other concurrent reinforcers were removed. This result is inconsistent with hypotheses that time allocation or response rates are simple functions of relative reinforcement rates.

EXPERIMENT 3

In Experiment 3 a brief auditory stimulus was presented when reinforcement became available. The purpose was to address two questions: First, would collateral activity be maintained when stimulus support was provided for the operant? Second, if collateral activities were maintained, would they be related to operant responding as found in the first two experiments?

METHOD

Subjects

Four 150-day-old, naive, male hooded rats were maintained as in previous experiments.

Apparatus

Same as in previous experiments.

Procedure

All experimental sessions were between 50 and 65 min in length and were conducted five days per week. Lever-press shaping took place in the first session with the rat locked in C_4 (the Closed condition). Beginning with Session 2 the rats were allowed unrestricted access to all 10 compartments of the experimental chamber (the Open condition). Sessions 2 through 5 consisted of delivering a food pellet following every fifth lever press. During Sessions 6 through 12 the schedule of reinforcement gradually changed to DRL 28-sec where it remained for the duration of the experiment. Beginning with Session 13, a 1000

Hz, 85-db tone of .5-sec duration was presented by a speaker located above C_4 when 28 sec had elapsed since the previous lever press (the Tone condition), thereby signaling the availability of lever-press-dependent food. Behavior stabilized in the Open-Tone condition from Sessions 13 through 28. Beginning with Session 29 and every third session thereafter through Session 44, a condition other than Open-Tone was present for one session. In the Closed-Tone condition the rat was locked in C_4 by closing a door over the exit, and the tone continued to be presented when food became available. In the Open-No Tone condition access to all compartments was unrestricted, but the tone was not presented at the beginning of the reinforceable interval. In the Closed-No Tone condition, the rat was locked in C_4 and the tone was not presented. Each of the three conditions was presented twice with two sessions of Open-Tone between each of the other conditions. The order of the conditions was random with the restriction that each of the conditions was presented once before any condition was present for the second time.

RESULTS AND DISCUSSION

Figure 14 shows the mean lever-pressing rates and Figure 15 shows the mean rates of food presentation for each rat in each condition.

Closed-Tone

Two rats (1 and 2) increased lever-pressing rates above Open-Tone levels in the Closed-Tone condition and two rats (3 and 4) showed no change. The cumulative records in Figure 16 demonstrate that the increased rates of lever pressing that occurred in the Closed-Tone condition for Rats 1 and 2 occurred during the first part of the session. Thereafter, the cumulative records of the Closed-Tone sessions are indistinguishable from those obtained during the Open-Tone sessions. The lever-pressing IRT distributions in Figure 17 also show that the temporal regularity of the operant was little affected by locking the rats in C_4 in the Closed-Tone condition. Rats 1 and 2 maintained a modal IRT of 28 to 32 sec in the Closed-Tone condition, but there was a greater proportion of IRTs < 28 sec than in the Open-Tone condition. Rats 3 and 4 had a greater proportion of 28 to 32-sec IRTs in the Closed-Tone condition than in the Open-Tone condition. If the initiation of lever pressing was mediated by some property of collateral activities per se, it would be expected that the Closed-Tone condition would result in either an increased or decreased rate of lever pressing. The results of the Closed-Tone condition showed relatively small, transitory effects on lever pressing for three of the four rats.

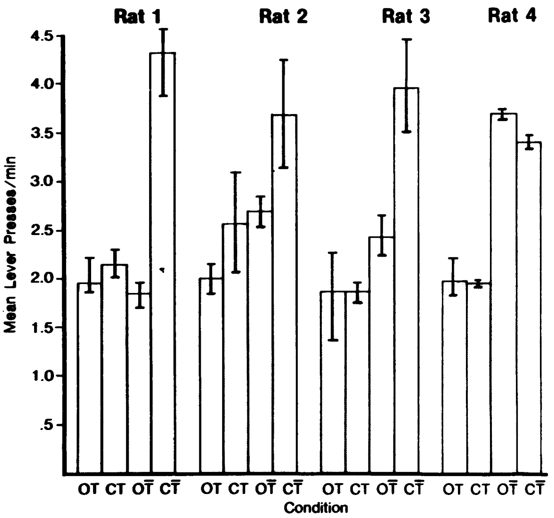

Fig. 14. The mean rate of lever pressing for each rat in each experimental condition. The mean for the Open-Tone condition for each rat is from the six sessions immediately preceding each of the other three conditions. The means for each condition other than Open-Tone are from two sessions each. OT = Open-Tone, CT = Closed-Tone, O$\bar{T}$ = Open-No Tone, and C$\bar{T}$ = Closed-No Tone. Brackets represent the range of individual session results.

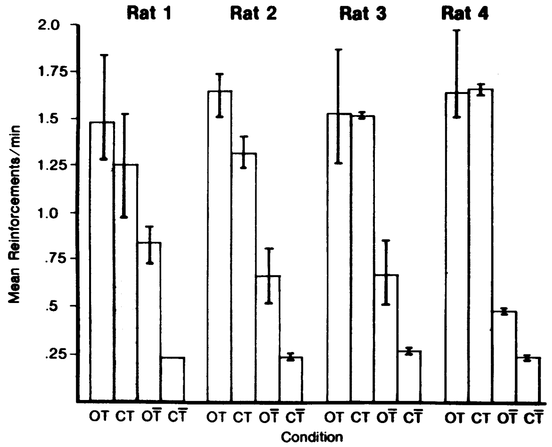

Fig. 15. Mean rates of food presentation for each rat in each condition, presented as in Figure 14.

Open-No Tone

In the Open-No Tone condition three of the four rats lever pressed at higher rates than in the Open-Tone condition and all four rats received reduced rates of food presentation. The lever-pressing IRT distributions for all rats in Figure 17 show that the Open-No Tone condition flattened the distribution and shifted the modal IRT to less than 28 sec for three of the four rats. The Open-No Tone condition was simply an unsignaled DRL, which allowed for the maintenance of any established collateral activities. If the temporal pattern of lever pressing in the Open-Tone condition was a simple function of some property of established collateral activities, it would be expected that the temporal regularity of lever pressing would not be greatly affected by the removal of the tone.

Closed-No Tone

In the Closed-No Tone condition the rates of lever pressing increased above Open-Tone levels for all rats and the rate of food presentation was reduced. The IRT distributions in Figure 17 show that discriminative control of lever pressing was greatly reduced in all instances. Rates of lever pressing were maintained at levels consistent with those observed in the Closed condition of Experiment 1.

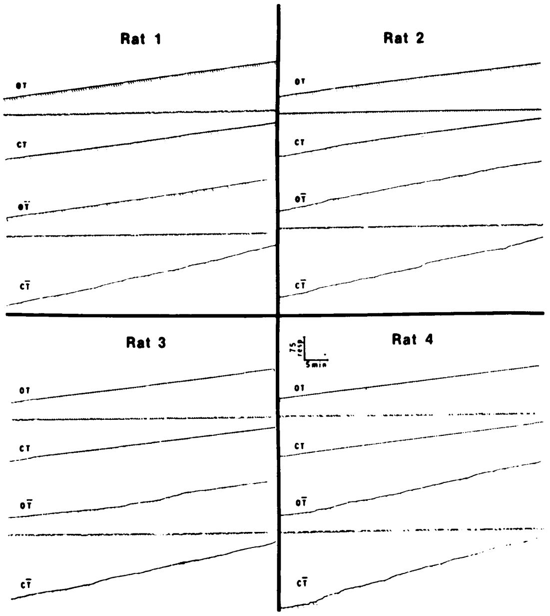

Fig. 16. Representative cumulative records for each rat in each condition. Pips represent food presentation. The event marker indicates presence in (down) and absence from (up) the food compartment. OT = Open-Tone, CT = Closed-Tone, O$\bar{T}$ = Open-No Tone, and C$\bar{T}$ = Closed-No Tone.

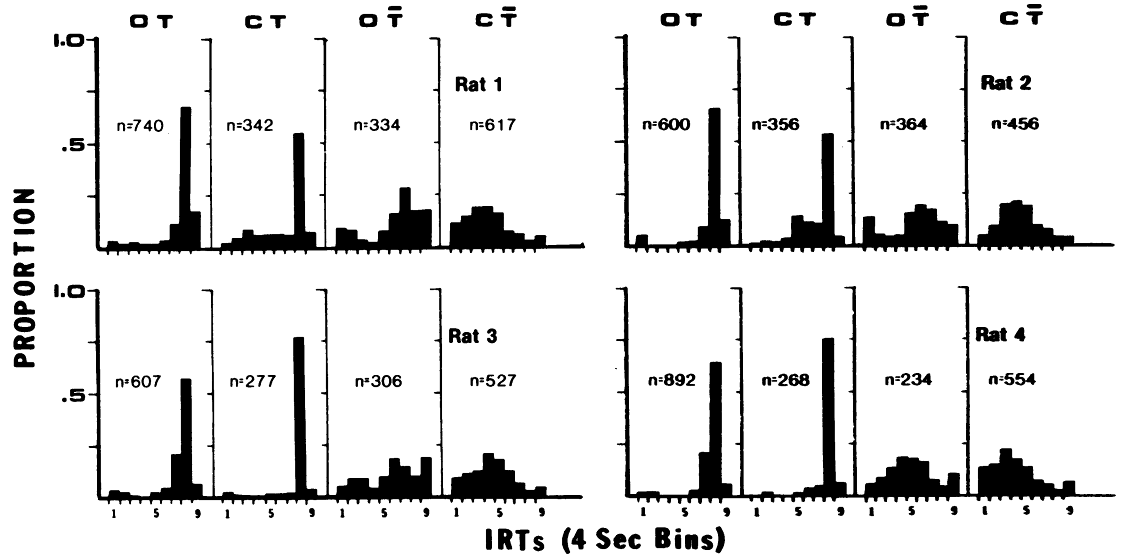

Fig. 17. Lever-pressing IRT distributions for each rat in each condition. The Open-Tone distribution is based upon the six sessions immediately preceding each of the other three conditions. The other distributions represent two sessions each. The total number of lever presses from which each distribution was calculated is represented above that distribution. OT = Open-Tone, CT = Closed-Tone, O$\bar{T}$ = Open-No Tone, and C$\bar{T}$ = Closed-No Tone.

Conclusions

Recently, Staddon (1977) has broadened competition theory and addressed the issue of temporal predictability by proposing that interim and terminal responses correspond to "states" of the organism that interact and increase or decrease with time since reinforcement. The states are the result of "causal factors" that are environmental in origin, i.e., discriminative and eliciting stimuli, time, antecedent activities, etc. Using the competing state model, many predictions can be made about temporal order in behavior depending upon the assumptions made about the strengths, durations, and decay functions of the various states and their relationship to behavior. Using a state model to explain the results of Frank and Staddon (1974), Staddon (1977) concluded that, "Figure 7B makes it clear that any reduction in the CFs [causal factors] for the interim activity, relative to those for the terminal response, will cause the terminal response to occur earlier in the interval, as Frank and Staddon found" (p. 147).

The results of Experiment 2 did not substantiate this conclusion. Removing and manipulating the "causal factors" (compartments) of collateral activities affected the rates of food presentation only when the rats were prevented from leaving the food compartment. In Experiment 3, if the presence of the rats in the compartments was in any way related to their "states" and if the timing of entry to the food compartment and the emission of the lever press were dependent upon the presence of the preceding states, then the Closed-Tone condition should have caused large increases or decreases in lever-pressing rates. Only one of the four rats showed a reliable change in lever-pressing rate in the Closed-Tone condition.

GENERAL DISCUSSION

The combined results of the experiments are difficult to interpret from any of the systematically formulated hypotheses that collateral activities have (a) timekeeping or discriminative functions or (b) inhibitory effects on the operant response. Weak inhibition hypotheses that simply propose that collateral activities interfere with the occurrence of the operant response (e.g., Hemmes et al., 1979) are not directly testable without a more precise specification of the theoretical or physical properties of inhibition. However, future inhibition hypotheses must account for the results of Experiment 2 in which the timing of the lever press was relatively unaffected by the manipulation and deletion of collateral activities.

The hypothesis that collateral activities develop to compensate for a process of temporal inhibition affecting the operant response is not directly testable in its present formulation. However, there is little evidence to support this hypothesis. Although the frequency of "misbehavior" related to feeding (handling, chewing, etc.) will be affected by the nature of the stimuli correlated with food presentation (Timberlake, Wahl, & King, 1982), there is little evidence that any schedule-induced activity, except drinking, has been raised above its operant level (Roper, 1981). Moreover, schedule-induced drinking may be amenable to an interpretation based on normal reinforcement mechanisms (Keehn & Riusech, 1979).

The results of the present experiments are readily explained by the hypothesis that collateral activities facilitate long operant IRTs by removing the subject from the presence of the manipulandum (McGown et al., 1977). This hypothesis has several implications. First, enlarging the size of the operant chamber (Skuban & Richardson, 1975) or providing stimuli for collateral activities may both serve a common function. Second, collateral activities assume no special status as a response class with regard to the operant. Third, an understanding of temporal control will probably not come from an analysis of the structure of collateral activities.

Fourth, this hypothesis is consistent with results obtained from the use of "self-control" schedules with both pigeons (Grosch & Neuringer, 1981) and humans (Mischel, Ebbesen, & Zeiss, 1972). Self-control schedules generally present a more preferred reinforcer for a response occurring after a minimum specified duration and a less preferred reinforcer if the response occurs prior to the end of the duration. For both pigeons and children, providing stimuli for an alternative response increases the number of preferred reinforcers obtained. Although these results can be accounted for by a response-inhibition hypothesis, both Grosch and Neuringer (1981) and Mischel et al. (1972)

used an alternative explanation. Grosch and Neuringer (1981) concluded that adding an alternative response manipulandum provided an escape from the self-control stimulus, and/or engaging in the alternative response had an increased probability of being followed by the preferred reinforcer. Mischel et al. (1972) found that children given a toy during the waiting interval received more of the preferred reinforcers than children not given a toy. The toy's effect was interpreted as drawing the children's attention away from the reinforcers. Both of these interpretations are consistent with the conclusions of McGown et al. (1977) regarding collateral activities during DRL schedules and with the results of the present experiments.

REFERENCES

Baum, W. M., & Rachlin, H. C. Choice as time allocation. *Journal of the Experimental Analysis of Behavior,* 1969, **12,** 861-874.

Frank, J., & Staddon, J. E. R. Effects of restraint on temporal discrimination behavior. *Psychological Record,* 1974, **24,** 123-130.

Glazer, H., & Singh, D. Role of collateral behavior in temporal discrimination performance and learning in rats. *Journal of Experimental Psychology,* 1971, **91,** 78-84.

Grosch, J., & Neuringer, A. Self-control in pigeons under the Mischel paradigm. *Journal of the Experimental Analysis of Behavior,* 1981, **35,** 3-21.

Hemmes, N. S., Eckerman, D. A., & Rubinsky, H. J. A functional analysis of collateral behavior under differential-reinforcement-of-low-rate schedules. *Animal Learning and Behavior,* 1979, **7,** 328-332.

Hemmes, N. S., & Rubinsky, H. J. Conditioned acceleration and external disinhibition of operant lever pressing by prereward, neutral, and reinforcing stimuli. *Journal of the Experimental Analysis of Behavior,* 1982, **38,** 157-168.

Keehn, J. D., & Riusech, R. Schedule-induced drinking facilitates schedule-controlled feeding. *Animal Learning and Behavior,* 1979, **7,** 41-44.

Laties, V. G., Weiss, B., Clark, R. L., & Reynolds, M. D. Overt "mediating" behavior during temporally spaced responding. *Journal of the Experimental Analysis of Behavior,* 1965, **8,** 107-116.

Laties, V. G., Weiss, B., & Weiss, A. B. Further observations on overt "mediating" behavior and the discrimination of time. *Journal of the Experimental Analysis of Behavior,* 1969, **12,** 43-57.

McGown, W. P., Spencer, W. B., & Neetz, R. An investigation of collateral wood-chewing as a time-mediational device. *Psychological Reports,* 1977, **41,** 1063-1069.

Mischel, W., Ebbesen, E. B., & Zeiss, A. R. Cognitive and attentional mechanisms in delay of gratification. *Journal of Personality and Social Psychology,* 1972, **21,** 204-218.

Richardson, W. K., & Loughead, T. E. The effect of physical restraint on behavior under the differential-reinforcement-of-low-rate schedule. *Journal of the Experimental Analysis of Behavior,* 1974, **21,** 455-461.

Richelle, M., & Lejeune, H. *Time in animal behaviour.* New York: Pergamon Press, 1980.

Roper, T. J. What is meant by the term "schedule-induced," and how general is schedule induction? *Animal Learning and Behavior,* 1981, **9,** 433-440.

Schwartz, B., & Williams, D. R. Discrete-trials spaced responding in the pigeon: The dependence of efficient performance on the availability of a stimulus for collateral pecking. *Journal of the Experimental Analysis of Behavior,* 1971, **16,** 155-160.

Skuban, W. E., & Richardson, W. K. The effect of the size of the test environment on behavior under two temporally defined schedules. *Journal of the Experimental Analysis of Behavior,* 1975, **23,** 271-275.

Smith, J. B., & Clark, F. C. Effects of *d*-amphetamine, chlorpromazine, and chlordiazepoxide on intercurrent behavior during spaced-responding schedules. *Journal of the Experimental Analysis of Behavior,* 1975, **24,** 241-248.

Staddon, J. E. R. A note on the analysis of behavioral sequences in *Columba livia. Animal Behaviour,* 1972, **20,** 284-292.

Staddon, J. E. R. Schedule-induced behavior. In W. K. Honig & J. E. R. Staddon (Eds.), *Handbook of operant behavior.* Englewood Cliffs, N.J.: Prentice-Hall, 1977.

Staddon, J. E. R., & Ayres, S. L. Sequential and temporal properties of behavior induced by a schedule of periodic food delivery. *Behaviour,* 1975, **54,** 26-49.

Staddon, J. E. R., & Simmelhag, V. L. The "superstition" experiment: A reexamination of its implications for the principles of adaptive behavior. *Psychological Review,* 1971, **78,** 3-43.

Timberlake, W., Wahl, G., & King, D. Stimulus and response contingencies in the misbehavior of rats. *Journal of Experimental Psychology: Animal Behavior Processes,* 1982, **8,** 62-85.

Wilson, M. P., & Keller, F. S. On the selective reinforcement of spaced responses. *Journal of Comparative and Physiological Psychology,* 1953, **46,** 190-193.

Received September 24, 1981
Final acceptance November 12, 1982