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SPACED RESPONDING IN MULTIPLE DRL SCHEDULES[1]

J. ZIMMERMAN[2] AND C. R. SCHUSTER

UNIVERSITY OF MARYLAND

Rats were able to adjust to two different temporal requirements within several multiple DRL schedules of reinforcement, and a slight induction between pairs of components was found. Initial administration of *dl*-amphetamine differentially disrupted spaced responding in the components of a multiple DRL 36 DRL 18 schedule, but did not eliminate discrimination between the components. After maximum drug effects, the continued administration of *dl*-amphetamine was accompanied by a progressive recovery of the behavior towards the characteristics of saline control.

Schuster and Zimmerman (1961) examined the action of chronic *dl*-amphetamine administration on spaced responding generated by a DRL schedule of reinforcement. The present report describes the behavior generated by multiple DRL schedules of reinforcement and the effects of chronic *dl*-amphetamine administration on such behavior.

PROCEDURE

Four albino rats performed daily on a multiple schedule which consists of one 36-sec DRL component and one 18-sec DRL component, with two 3-min TO periods sandwiched between. A tone was presented continuously during the DRL 36 component, but not during the DRL 18 component. Appropriately spaced responses in either DRL component were reinforced with 0.1 cc of sweetened condensed milk. Each experimental session started with the DRL 36 component, and continued the alternation of the two DRL components until four cycles of the multiple schedule were completed. In a given cycle, the DRL 18 component was presented for 8 min and the DRL 36 component for 16 min, so that subjects could obtain an equal number of reinforcements in each component.

After the final performance on the DRL 36 DRL 18 schedule, the experimental conditions were altered. Each subject was run through a different series of experimental conditions as shown in Table 1. For example, after the final performance on DRL 36 DRL 18 (Condition I). Rat H was given saline (i.p.) 5 min before a session, and this *S* performed on two cycles of the schedule for 10 daily sessions (Condition II). The *dl*-amphetamine (1.0 mg/kg) was then given daily instead of saline for 35 sessions (Condition III). Rat H performed with saline administration for 8 sessions (condition IV), and was then returned to the base-line, 4-cycle session for 9 sessions (Condition V). For the next 6 daily sessions, the DRL 36 component was removed from the multiple schedule and replaced with blackout while the DRL 18 component remained intact (Condition VI). The DRL 36 DRL 18 schedule was reinstated for 8 sessions (Condition VII). The DRL 36 component was then replaced with a DRL 27 component, and Rat H performed on the resulting multiple DRL 27 DRL 18 for 29 daily sessions (Condition VIII), and so on.

In order to compare the spaced-responding behavior generated by the different DRL components, a series of 10 counters tabulated the inter-response time frequencies for each component. For a given component, the range of the tabulated inter-response times was equal to twice the DRL value, and the class interval (amount of time) covered by each counter was 1/10th of that range. For example, the ranges for the DRL 36 and DRL 18 components were 72 sec and 36 sec, respectively. The class intervals were 7.2 sec and 3.6 sec, respectively.

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[2]Now at Indiana University Medical Center.

Table 1
Sequence of Experimental Conditions

Condition	*Rat JZ-2*	*No. of Sessions*	*Rat T-2*	*No. of Sessions*	*Rat H*	*No. of Sessions*	*Rat 9*	*No. of Sessions*
I	DRL 36 DRL 18	75	DRL 36 DRL 18	111	DRL 36 DRL 18	85	DRL 36 DRL 18	74
II	DRL 18 only	7	DRL 18 only	9	DRL 36 DRL 18 2 cycles, saline	10	DRL 18 only	12
III	DRL 36 DRL 18	11	DRL 36 DRL 18	15	DRL 36 DRL 18 2 cycles, chronic *dl*-amphet. (1.0 mg/kg)	35	DRL 36 DRL 18	10
IV	DRL 54 DRL 18	39	DRL 54 DRL 18	22	DRL 36 DRL 18 2 cycles, saline	8	DRL 36 DRL 18 2 cycles, saline	10
V	DRL 18 only	9	DRL 72 DRL 18	41	DRL 36 DRL 18	9	DRL 36 DRL 18 2 cycles, chronic *dl*-amphet. (0.6 mg/kg)	12
VI	DRL 54 DRL 18	13	DRL 18 only	13	DRL 18 only	6	DRL 36 DRL 18 2 cycles, saline	12
VII	DRL 72 DRL 18	29	DRL 72 DRL 18	9	DRL 36 DRL 18	8		
VIII	DRL 18 only	11			DRL 27 DRL 18	29		
IX	DRL 72 DRL 18	10			DRL 18 only	6		
X	DRL 36 DRL 18	9			DRL 27 DRL 18	18		
XI	DRL 36 DRL 18 2 cycles, saline	12			DRL 22.5 DRL 18	17		
XII	DRL 36 DRL 18 2 cycles, chronic *dl*-amphet. (1.0 mg/kg)	35			DRL 18 DRL 18	12		
XIII	DRL 36 DRL 18 2 cycles, saline	11						

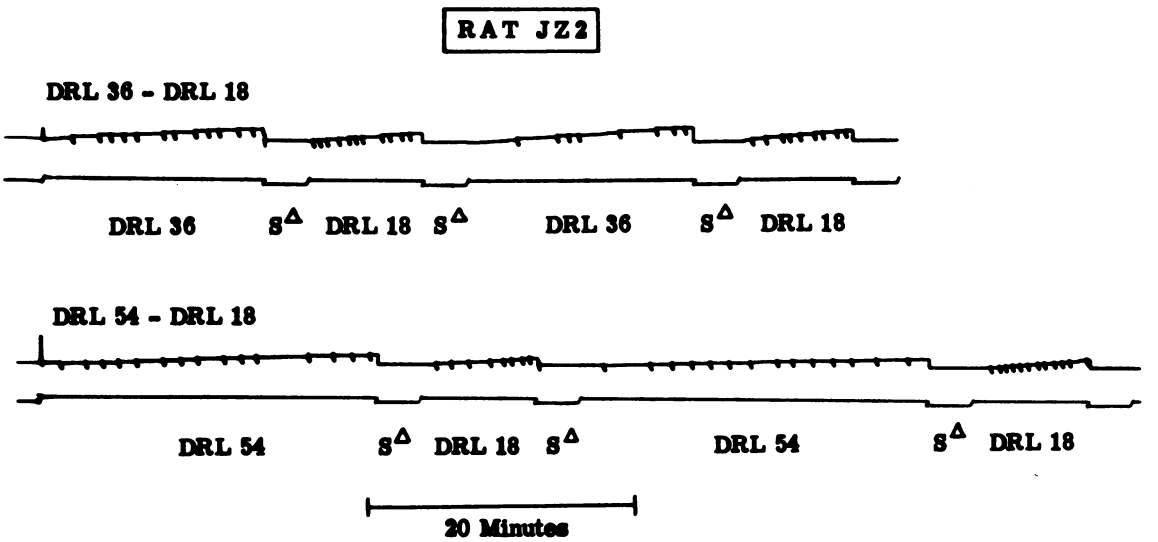

Fig. 1. Cumulative records for Rat JZ-2 from 2 cycles of the final performance on DRL 36 DRL 18 and DRL 54 DRL 18. Upper (response) pen resets after each component. Lower (condition) pen is displaced downward during the 3-min S^{Δ} periods.

RESULTS

Behavioral Data for Rats JZ-2, T-2, and H

Figure 1 presents cumulative records for Rat JZ-2 taken from the final performances on DRL 36 DRL 18 (Condition I) and DRL 54 DRL 18 (Condition IV). The behavior must have come under stimulus control because (a) responding in the S^{Δ} periods was almost completely absent; (b) differential response rates were maintained that were appropriate to the particular DRL contingencies; and (c) approximately equal numbers of reinforcements (pips) were obtained in each component. Figure 2, Column A, presents averaged, relative-frequency distributions of inter-response times for Rat JZ-2, for the final three sessions on DRL 36 DRL 18, DRL 54 DRL 18, and DRL 72 DRL 18. For each multiple schedule, the distributions were well separated and appropriate to the specific DRL contingencies. That is, the modal value of each distribution was close to the earliest IRT interval in which reinforcement could occur. Figure 3, Column A, presents similar data for Rat T-2. Figure 4, Column A, presents similar data for Rat H for the final performances on DRL 36 DRL 18; DRL 27 DRL 18; DRL 22.5 DRL 18; and DRL 18 DRL 18. Again, the distributions for each multiple schedule (except for DRL 18 DRL 18) were well separated and appropriate to the specific DRL contingencies.

As a further comparison of the behavior generated by the two components in each multiple schedule, the distributions in Column A were replotted in Column B. The number of each counter (IRT interval) was plotted on the abscissa in place of the absolute time value covered by each counter. There-

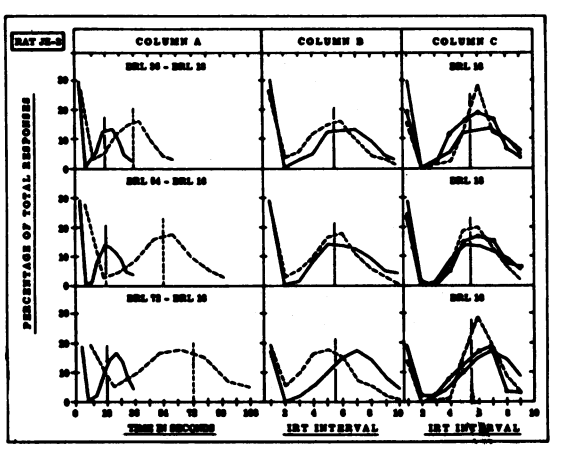

Fig. 2. Column A: Averaged relative-frequency distributions of IRT's from three final sessions of each multiple DRL schedule for Rat JZ-2, solid distributions represent DRL 18 and dotted distributions represent higher-valued DRL behavior; and horizontal lines denote the respective DRL values. Column B: Distributions in Column A replotted as a function of the particular number of the IRT interval. Column C: Relative-frequency distributions of DRL 18 only, from the final three sessions before (solid lines), during (dashed lines), and after (solid lines with solid dots) the removal of the higher-valued DRL component.

fore, the distributions in Column B were plotted on a relative rather than absolute time basis. That is, the entire range of each distribution covered the same horizontal distance. Plotted in this way, the distributions from a given multiple schedule can be compared with respect to their overall shape and location relative to their respective DRL values. Many of the pairs of distributions plotted in Column B of Fig. 2, 3, and 4 approach superimpos-

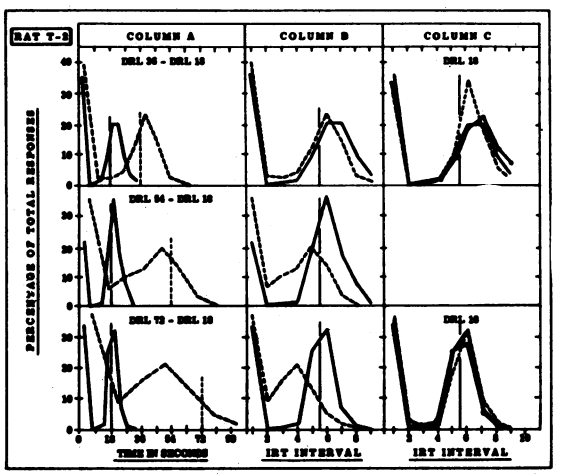

Fig. 3. Column A: Averaged relative-frequency distributions of IRT's from three final sessions of each multiple DRL schedule for Rat T-2; solid distributions represent DRL 18 and dotted distributions represent higher-valued DRL behavior; and horizontal lines denote the respective DRL values. Column B: Distributions in Column A replotted as a function of the particular number of the IRT interval. Column C: Relative-frequency distributions of DRL 18 only, from the final three sessions before (solid lines), during (dashed lines), and after (solid lines with solid dots) the removal of the higher-valued DRL component.

ability. However, for all but one pair, the distribution from the DRL 18 component was always displaced towards higher IRT intervals relative to the distribution from the higher-valued DRL component. The only exception was for Rat H (Fig. 4.), for which both components were identical (DRL 18). This reliable observation suggested a possible interaction or induction between the components in each multiple schedule. However, the results might have been the same for behavior generated by the separate DRL components if they had been programmed separately.

Induction Between Components

The higher-valued component was sometimes removed from the multiple schedule and replaced by a blackout condition in order to test for the possibility of induction between components. After the performance had stabilized in the isolated DRL 18 component, the original conditions were reinstated. Column C of Fig. 2, 3, and 4 present distributions from the DRL 18 components run in isolation. In all but one instance, the removal of the higher-valued component from a multiple schedule was followed by a shift in the DRL 18 distributions in the direction of a more pronounced mode. In these instances, a return to the multiple schedule was followed by the reversal of this effect. This effect was not observed with Rat T-2 for the DRL 72 DRL 18 series, and was barely observed with Rat H for the DRL 27 DRL 18 series.

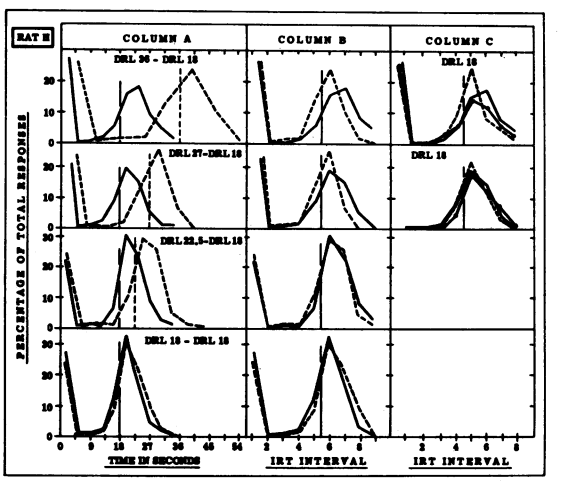

Fig. 4. Column A: Averaged relative-frequency distributions of IRT's from three final sessions of each multiple DRL schedule for Rat H; solid distributions represent DRL 18 and dotted distributions represent higher-valued DRL behavior; and horizontal lines denote the respective DRL values. Column B: Distributions in Column A replotted as a function of the particular number of the IRT interval. Column C: Relative-frequency distributions of DRL 18 only, from the final three sessions before (solid lines), during (dashed lines), and after (solid lines with solid dots) the removal of the higher-valued DRL component.

Reinforcement Ratio

Another aspect of the DRL performance is the ratio of the number of reinforcements obtained in the higher-valued DRL component to the number of reinforcements obtained in the DRL 18 component. These ratios were computed from the data of the same sessions from which the distributions in Columns A and B were plotted. Table 2

shows the resulting "reinforcement ratios." A ratio of close to 1.0 indicates that a subject obtained an approximately equal number of reinforcements in both components. All three subjects did obtain an approximately equal number of reinforcements in both components of the DRL 36 DRL 18 multiple schedule. On all schedules, Rat H and Rat JZ-2 had approximately equal reinforcement frequencies in both DRL components. However, Rat T-2, relative to its behavior on DRL 18, was not able to meet the behavior requirement of DRL 54 (ratio of 0.56), and even less able to meet the requirement of DRL 72 (ratio of 0.28).

Table 2
Reinforcement Ratio

Condition*	Reinforcement Ratio		
	Rat JZ-2	Rat T-2	Rat H
DRL 36 DRL 18	1.11	1.05	1.04
DRL 54 DRL 18	1.00	0.56	
DRL 72 DRL 18	0.83	0.28	
DRL 27 DRL 18			1.01
DRL 22.5 DRL 18			1.04
DRL 18 DRL 18			0.97
DRL 36 DRL 18 Drug Sessions			
C_1	0.93		0.97
D_1	0.49		0.47
D_2	0.54		0.47
D_3	0.51		0.54
D_4	0.44		0.46
C_2	0.77		0.85

*Final performance.

Pharmacological Data for Rats JZ-2 and H

Figure 5 presents averaged frequency distributions of IRT's for Rat JZ-2 and Rat H from six predrug saline control sessions (C_1); from the first, second, third, and fourth quarters of the *dl*-amphetamine sessions (D_1, D_2, D_3, and D_4, respectively); and from six postdrug saline sessions (C_2). In the initial *dl*-amphetamine sessions (D_1), the distributions for both DRL components increased markedly in the frequency of short IRT's compared with the distributions for saline control (C_1). The maximum drug effect occurred during the second quarter of the drug sessions (D_2). However, the distributions from both components shifted progressively towards the reinforced IRT intervals from D_2 to D_3 to D_4. Such effects were reported earlier for a simple DRL schedule of reinforcement (Schuster & Zimmerman, 1961).

Figure 5 shows that the multiple schedule provided additional information about the interaction between spaced responding and *dl*-amphetamine. The *dl*-amphetamine administration (D_1) resulted in a slight differential

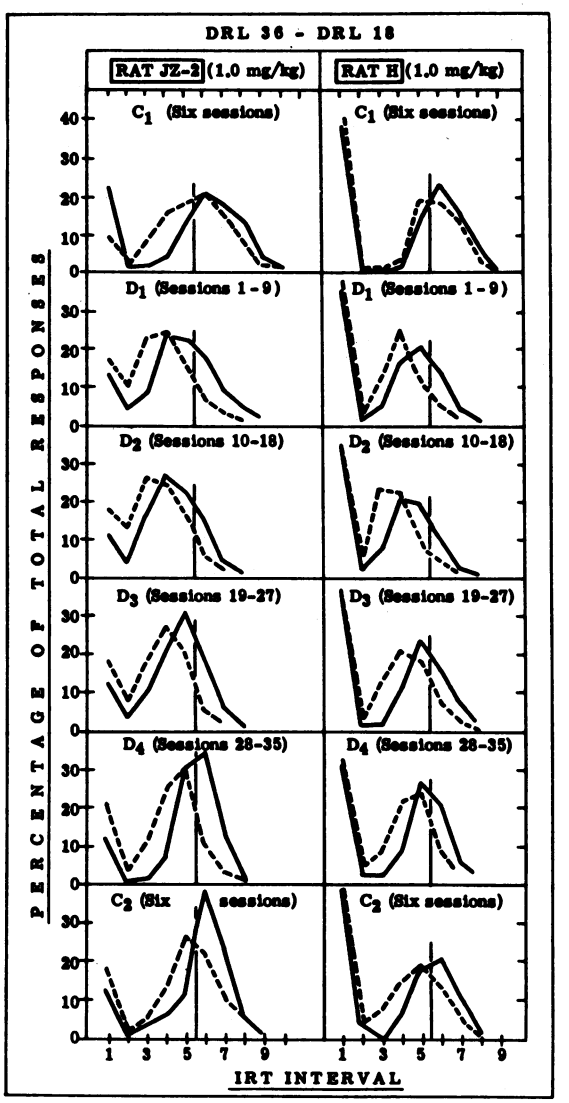

Fig. 5. Averaged relative-frequency distributions of IRT's for Rat JZ-2 (left column) and Rat H (right column) from predrug saline control sessions (C_1); from the first, second, third, and fourth quarters of the *dl*-amphetamine sessions (D_1, D_2, D_3, D_4, respectively); and from postdrug saline control sessions (C_2).

effect on the two components of the multiple schedule. The initial shift of the DRL 36 distribution towards shorter IRT intervals was more pronounced than the initial shift of the DRL 18 distribution, but differential control by the two schedules was not eliminated. During the progressive return of the distributions towards higher IRT intervals (from D_2 to D_3 to D_4), the initial differential effect was not eliminated; instead, the two distributions shifted back at approximately the same rate. The reinforcement ratios in the lower half of Table 2 demonstrate correlated observations. Initial *dl*-amphetamine administration (D_1) lowered the reinforcement ratio to approximately 0.50 for both animals. (Compared with control values close to 1.0 at C_1, the animals were now obtaining about twice as many reinforcements in the DRL 18 component as in the DRL 36 component.) Over the entire drug regimen, the ratios remained at approximately 0.50.

In other words, the initial differential effect of the drug on the two components with respect to reinforcement ratio was maintained over the drug regimen even though the behavior in both components was shifted towards base-line behavior and the absolute number of reinforcements obtained per session was increasing. When the drug was discontinued (C_2), the performance returned to normal without any overcompensation, and approached the behavior in the predrug sessions (C_1).

Data for Rat 9:
Atypical Behavior and "Drug Therapy"

Figure 6A presents averaged relative-frequency distributions of IRT's for the final three sessions of DRL 36 DRL 18 for Rat 9. Although the distributions from the two components are well separated, the modal value of the DRL 18 distribution occurred at 24 to 27 sec, two class intervals higher than the earliest IRT interval in which responses were reinforced. The modal value of the DRL 36 distribution occurred right at the DRL value. The replot of the data in Fig. 6B shows the marked contrast in the relative positions of the two distributions in relation to their respective DRL values. To test the possibility of an extreme induction effect, the DRL 36 component was removed from the multiple schedule. The DRL 18 distribution was not a function of the presence of the DRL 36 component. As Fig. 6C shows, the removal of the DRL 36 component did not change the characteristics of the DRL 18 distribution. On the basis of these data and data for other rats run on DRL schedules of reinforcement, the behavior of Rat 9 was considered atypical because the DRL behavior of most rats generate IRT distributions whose modes lie close to the DRL value.

Rat 9 was therefore placed on a chronic drug regimen (0.60 mg/kg *dl*-amphetamine) which was designed to shift the DRL 18 distribution towards shorter IRT intervals so

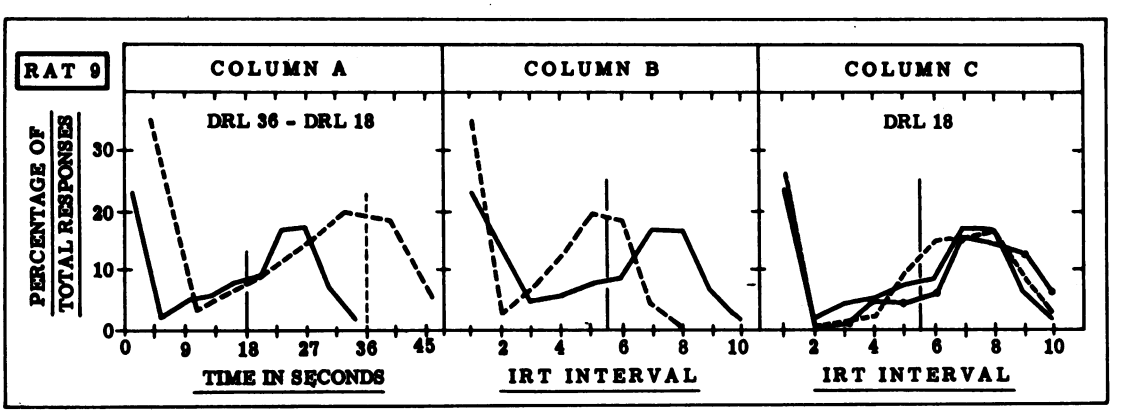

Fig. 6. Column A: Averaged relative-frequency distributions of IRT's from three final sessions of DRL 36 DRL 18 for Rat 9; solid distributions represent DRL 18 and dotted distributions represent higher-valued DRL behavior; and horizontal lines denote the respective DRL values. Column B: Distributions in Column A replotted as a function of the particular number of the IRT interval. Column C: Relative-frequency distributions of DRL 18 only, from the final three sessions before (solid lines), during (dashed lines), and after (solid lines with solid dots) the removal of the higher-valued DRL componenent.

that its modal value would lie at or near the DRL value. Figure 7 presents relative-frequency distributions for Rat 9 for the predrug

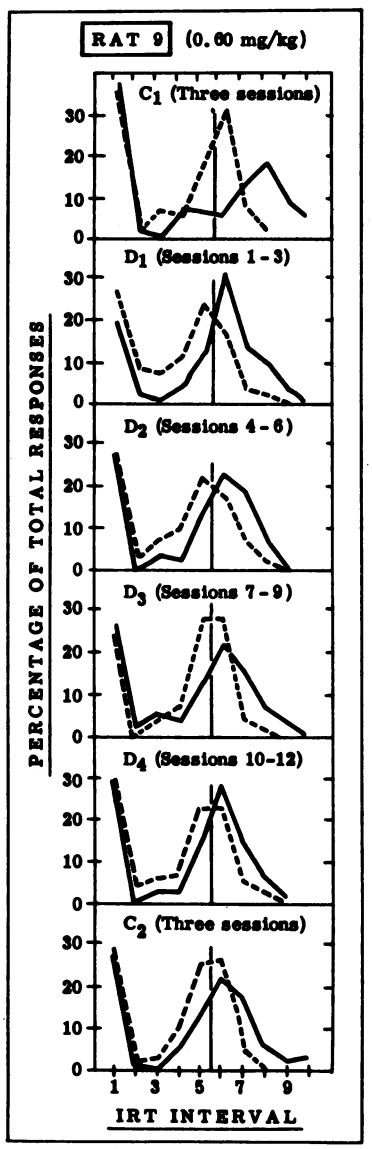

Fig. 7. Averaged relative-frequency distributions of IRT's for Rat 9 from predrug saline control sessions (C_1); from the first, second, third, and fourth quarters of the *dl*-amphetamine sessions (D_1, D_2, D_3, D_4, respectively); and from postdrug saline control sessions (C_2).

saline, drug, and postdrug saline sessions. With initial *dl*-amphetamine administrations (D_1), the distributions from both components increased in the frequency of short IRT's compared with the distributions for saline control (C_1). The initial administration of the drug (D_1) shifted the DRL 18 distribution more than the DRL 36 distribution. The modal value of the DRL 18 distribution was shifted to the earliest IRT interval in which a response was reinforced. Over the next 9 sessions of drug administration (D_2, D_3, and D_4), a slight return towards control values occurred in the DRL 36 distribution, whereas little change occurred in the DRL 18 distribution. The DRL 18 distribution did not return to its earlier "atypical" value during the postdrug saline sessions (C2), nor did any further changes occur through the 12 postdrug saline sessions.

DISCUSSION

With respect to the general characteristics of spaced responding in the individual DRL components, the present data confirm results reported previously by other investigators (*e.g.*, Wilson & Keller, 1953; Sidman, 1955).

Wilson and Keller reported that the number of reinforcements obtained per hour varied inversely with the DRL value. However, they did not compare the schedules in terms of the efficiency of behavior with respect to reinforcement opportunities. In a given amount of time, different DRL schedules present different numbers of opportunities for subjects to be reinforced. In the present study, the opportunity to obtain a given number of reinforcements in a given multiple DRL schedule was made equal for both components by manipulating the duration of presentation of each component. The present results demonstrated that when given the opportunity, subjects were often able to obtain approximately equal numbers of reinforcements in each component. (See top portion of Table 2.)

The data suggested and confirmed an induction between components of the multiple DRL schedules. Although this study did not parametrically examine the variables of which the induction between components was a function, the data suggest two possible contributing factors. Although the characteristics of the DRL 18 distribution for Rat JZ-2 did not change significantly from DRL 36 DRL 18 to DRL 54 DRL 18 to DRL 72 DRL 18, the mode of the DRL 18 distribution for Rat T-2 became considerably more pronounced and shifted towards shorter IRT intervals in going from DRL 36 DRL 18 to DRL 54 DRL 18 and

DRL 72 DRL 18. Concomitantly, the reinforcement ratio changed relatively little over this series for Rat JZ-2, while the reinforcement ratio dropped markedly for Rat T-2, from DRL 36 DRL 18 to DRL 54 DRL 18 to DRL 72 DRL 18. Correlated with these observations, an induction effect was found for all three multiple schedules on which Rat JZ-2 performed; but for Rat T-2, it was found on DRL 36 DRL 18 but not on DRL 72 DRL 18. In other words, the induction effect was demonstrated whenever the reinforcement ratio was close to 1.0. In the instance in which no such effect was demonstrated (DRL 72 DRL 18 for Rat T-2), the reinforcement ratio was extremely low and the mode of the DRL 18 distribution was extremely pronounced, even in the presence of the intact multiple schedule. It is suggested that an induction effect may be obtained only when a subject is meeting the behavior requirements of each component fairly equally. Otherwise, the DRL 18 component may be in effect functioning "as if it were being presented in isolation."

The behavior of Rat H suggests a second factor that may affect induction. The superimposition of the pairs of IRT distributions was more marked from DRL 36 DRL 18 to DRL 27 DRL 18 to DRL 22.5 DRL 18 to DRL 18 DRL 18. Furthermore, through the same conditions, the modes of the distributions from DRL 18 become more pronounced and modal values were more distinctly in the earliest IRT interval in which reinforcements occurred. Consequently, induction between components may be a function of the specific component DRL values, and an optimal pair of values can possibly be programmed. Unfortunately, the removal of the higher-valued DRL component was examined only for DRL 36 DRL 18 and DRL 27 DRL 18. For these two series, however, the removal of the DRL 36 component resulted in greater change than the removal of the DRL 27 component.

The effect of chronic administration of *dl*-amphetamine on the behavior generated by the DRL 36 DRL 18 was similar to the effect found earlier for a simple DRL schedule (Schuster & Zimmerman, 1961). With the initial administrations of the drug, IRT distributions shifted toward shorter time intervals. After maximum drug effects were observed, both distributions progressively recovered toward saline control characteristics for the remainder of the drug regimens. The multiple schedule provided additional information about the *dl*-amphetamine-DRL interaction. Although the administration of *dl*-amphetamine did not eliminate differential control by the two DRL components, it exerted an initial differential effect on the behaviors. This initial effect was maintained throughout the chronic drug regimen.

The results with Rat 9 were given separately so that they could be presented as a cogent demonstration of the application of laboratory findings to a problem involving the alteration of atypical behavior. The behavior of Rat 9 on the DRL 18 component of the DRL 36 DRL 18 multiple schedule was observed to be atypical. After failure to account for the atypical behavior on the basis of earlier findings (induction effect), "drug therapy" was successfully used to alter the behavior, at least temporarily, toward more typical DRL behavior.

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