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The City University of New York, Ph.D., 1973
Psychology, experimental

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SCHEDULE CONTROL OF SIMULTANEOUS DISCRIMINATION

by

DENNIS MOURER

A dissertation submitted to the Graduate Faculty in Psychology in partial fulfillment of the requirements for the degree of Doctor of Philosophy, The City University of New York.

1973

This manuscript has been read and accepted for the Graduate Faculty in Psychology in satisfaction of the dissertation requirement for the degree of Doctor of Philosophy.

May 14, 1973
date

Chairman of Examining Committee

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THE CITY UNIVERSITY OF NEW YORK

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Introduction

In their introduction to Schedules of Reinforcement, Ferster and Skinner (1957, p. 2) distinguish between descriptive and theoretical lines of analysis in the study of reinforcement schedules. The first considers the schedule performance as a dependent variable. This level of analysis focuses upon the maintenance of stable schedule behavior in order to derive a precise description of the performance typically generated by each logical class of scheduling operation. Ferster and Skinner believe that the more general theoretical analysis is to be accomplished by "a closer analysis of the actual contingencies of reinforcement prevailing under any given schedule" (1957, p.2). These writers are confident that this inquiry will "answer the question of why a given schedule generates a given performance" (1957, p.2). A theoretical analysis is therefore concerned with an examination of specific controlling relations which underlie schedule performance.

In the fifteen years which have elapsed since the publication of Schedules of Reinforcement, a substantial amount of research has been directed toward a descriptive analysis of reinforcement schedules. As a result the rate patterns, which are maintained by the various time and response defined schedules, can be predicted with a relatively high degree of accuracy. In no instance is this predictability more apparent than in the case of the fixed-ratio (reinforcement for every n^{th} response) schedule. The familiar break-and-run pattern of responding (a period of non-response following reinforcement is terminated by an abrupt transition to a high and invariant rate of response which persists until the next reinforcement is delivered) is an almost invariant consequence of the fixed-ratio procedure. Although most research has utilized a simple response class such as a key peck or lever press, similar rate patterns have been demonstrated when more complex operants are maintained on fixed-ratio schedules. Ferster (1960) maintained a two-hue matching-to-sample problem on moderate value fixed-ratio schedules. The overall rate pattern was typical of that which would be expected of a simple key peck. The birds were either pausing or responding at high terminal rates. Similar data have been observed by Mintz, Mourer and Stein (1968).

The break-and-run pattern is not, however, the invariant consequence of fixed-ratio reinforcement. When the within-cycle distribution of response measures, other than simple rate, are examined, a different picture of fixed-ratio control may emerge. The zero delay matching-to-sample procedure employed by Mintz, Mourer and Weinberg (1966) may be taken as a case in point. Utilizing a discrete-trials procedure, these authors maintained a two-hue matching on a FR-9 schedule of reinforcement. Pigeons were used as subjects. Responses to the side key of matching hue advanced the ratio by one count and initiated a 350 msec delay before the onset of the next trial. Responses to the side key of contrasting hue delayed the start of the next trial by 6.0 seconds.

Examination of rate measures, whether based on single responses or the two-response sequence which constituted the match attempt, revealed the usual break-and-run pattern characteristic of FR performance. By contrast, the probability that a center key response would be followed by a response to the side key of matching hue was found to increase systematically across the sequence of unreinforced correct matches which constituted the ratio. Matching accuracy averaged 79.0% in the first cycle position and increased systematically to an average terminal value of 97.0%.

Thus we see that measures of performance beyond simple occurrence have permitted the emergence of a response pattern which would not have been anticipated from simple rate measures. It is important to emphasize once more that this gradient of accuracy - more reminiscent of fixed interval (FI) than FR control - is observed in conjunction with the more typical FR rate pattern.

A similar pattern of matching accuracy has also been observed by Nevin, Cumming and Berryman (1963). Their procedure differed from that of Mintz et al. (1966) only in that the problem involved simultaneous three-hue matching and required a short sequence of responses (FR-5) rather than a single response to produce the matching stimuli. After initial CRF training, in which overall accuracy exceeded 95%, each of the three animals were exposed to fixed-ratio values of three, six, and ten. Accuracy, which was reduced to chance levels immediately following reinforcement, increased systematically as the ratio was counted out. Terminal accuracy at all FR values closely approximated CRF levels. At completion of the FR-10, all animals were exposed to a VR-3 contingency. When responding was maintained on this schedule, the probability of a correct match was not depressed following reinforcement but maintained a uniformly high level of accuracy throughout the cycle. This suggests that the discriminative aspects of the schedule may exert substantial influence over within-cycle responding in the mature performance.

These general findings were subsequently confirmed by Stein (1968), whose procedure was a direct replication of the zero delay matching employed by Mintz, et al., and by Zeiler (1968), who employed a three-hue simultaneous discrimination maintained at fixed-ratio values from 50 to 150. Both of these investigators report the characteristic break-and-run fixed-ratio rate pattern.

Notterman and Mintz (1965) report similar findings when response force is reinforced on an FR schedule. Within the class of responses, a sub-class was defined in terms of the emission of a fixed minimum effort (time integral of force). Force emissions which fell short of the criterion were without effect. Examination of within-cycle response patterns revealed that the relative frequency of responses meeting the criterion was depressed following reinforcement and increased progressively over the course of the unreinforced response sequence. At the time Notterman and Mintz had to entertain the possibility that their subjects were simply responding in the more vigorous fashion characteristic of extinction, with the increase in frequency of responses meeting the criterion being merely coincidental. In consideration of the findings of Mintz et al. (1966) and Nevin et al. (1963), it may be more reasonable to forego an explanation based upon extinction and interpret this data as reflecting a more accurate discrimination of the effort criterion as reinforcement is approached.

Taken as a whole, this data serve to demonstrate the absence of a pandemic response pattern which is the invariant consequence of fixed-ratio reinforcement. Depending upon what aspect of the data is examined, available research leaves us with two very different pictures of the pattern of fixed-ratio control. First, the simple rate data are reminiscent of a threshold phenomenon in which the transition from minimum to maximum schedule control is completed in the course of the first few responses. On the other hand, the accuracy data is suggestive of a generalization gradient of reinforcement probability in which schedule control increases progressively with each response becoming asymptotic only in close proximity to reinforcement.

In contrast to the FR situation, Ferster (1960) has shown that when matching to sample is maintained on a FI-10 schedule, the accuracy data were found to be largely consistent with simple rate data taken during FI matching. Ferster computed accuracy measures over progressive quarters of the interval and found that with the exception of an inconsistent first quarter, there is a systematic increase in accuracy across the final three quarters of the interval. We now see that the distinctive rate patterns, which are characteristic of both FR and FI schedules of reinforcement, remain true to type when discriminations are maintained on these schedules. Notwithstanding the difference between the ratio and interval schedules, both seem to produce similar patterns of behavior when relative rate (accuracy) data is examined. In both cases the accuracy data is found to be suggestive of data typically occurring when a simple lever press or key peck is reinforced on a FI schedule. There is no a priori reason to expect a reinforcement schedule to exert the same pattern of control over all possible response measures. However, the observation that fixed-ratio and fixed-interval schedules behave differently in this regard may reflect fundamental differences between the stimulus control exerted by each schedule.

Although the effects of a wide range of schedule parameters have been determined for rate of response, very little research is available concerning variations in the quality or accuracy of performance produced by these parameters. The data which has just been reviewed suggests that an examination of within-cycle distributions of both response frequency and accuracy under various reinforcement contingencies might provide data useful in the explication of exact mechanisms of schedule control.

The observation that different response patterns may be maintained by the same schedule of reinforcement delivery can be restated in terms of differential stimulus control of rate and accuracy. At one level of analysis, it may be sufficient to say that both sets of controlling stimuli and thus both behavioral patterns are the consequence of the specific reinforcement contingency. However, it would also be desirable to relate momentary response probability to the immediately antecedent stimulus conditions and thus account more directly for the within-cycle response pattern. This may be characterized as an attempt to generate a causal analysis (cf Zeigler, 1964) of the schedule performance by isolating antecedent stimulus conditions which can be shown to be necessary and sufficient for control of the performance in question.

This type of analysis becomes a problem in the typical free operant procedure because momentary changes in the stimulus conditions confronting the organism are not normally under the experimenters' control. Controlling relations, other than reinforcement, are typically inferred from performance rather than experimentally demonstrated. This is understandable inasmuch as the continuous response sequences generated by free operant procedures all but preclude an analysis of the stimulus conditions controlling individual responses. A resolution of this problem may be approached through the use of a discrete-trials procedure in which the stimulus situation at each opportunity to respond is specified in advance. This methodology permits at least partial control of the stimulus complex immediately antecedent to the emission of each individual response.

The use of a discrete-trials procedure in the study of reinforcement schedules raises two important problems; both of which are direct results of the period of enforced non-response which is normally imposed between trials. First, the absence of true interresponse times precludes use of the response rate measures which are customary for free responding. The time between occurrence measure is necessarily translated into a latency measure: Time from onset of a trial to response. When a discriminated operant (e.g. Nevin, 1967) is employed, accuracy (relatively frequency) or probability data can also be utilized, but this data may not exactly replicate the information provided by traditional rate-of-response measures.

The loss of simple rate data may not, however, be a completely negative turn of events. It has been suggested elsewhere (Notterman & Mintz, 1965; Blough, 1965; Ray & Sidman, 1971) that the exclusive reliance on rate of response as a dependent variable may place limitations upon the theoretical generality of operant research. Utilizing response force as a dependent variable, Notterman and Mintz (1965) present a series of experiments which suggest that for a wide range of independent variables, "the dimensional characteristics of the response may be no less fundamental to the dynamic laws of the operant than rate of response" (p. 3). One of the logical consequences of this rather extensive series of experiments is the implication that regardless of the regularity or predictability of simple rate data, "there are fundamental theoretical and experimental issues, bearing on schedules of reinforcement, that demand more information than is provided by 'time-between-occurrence' measures." (Notterman & Mintz, 1965, p. 3)

Blough (1965) is critical of the unrestricted use of rate in generalization research. Blough points out that the overall rate is essentially a "conglomerate" compounded of several subsidiary rates (See also Blough, 1963), each largely under the control of different stimuli (i.e. previous response occurrence, stimulus onset, etc.). The absence of a simple unitary response measure, which can be properly quantified, is seen as retarding the development of research in the area of stimulus generalization.

This general argument is extended by Ray and Sidman (1970), who concern themselves with pointing up the distinction between using reinforcement to maintain rate of response in the presence of a given stimulus, and the problem of establishing and maintaining controlling stimulus-response relations. It is their contention that although "response rate has proven invaluable for assessing the effects of the response-reinforcement contingency, rate is not particularly suited ... to an investigation of the stimulus-response contingency" (p. 190).

Granted the basic importance of occurrence or non-occurrence of the response, the above work suggests that the loss of simple rate data may be a perfectly acceptable price to pay for the additional control over response which is provided by a discrete-trials methodology.

The second problem raised by the discrete-trials procedure is perhaps the more critical. The research to be presented here will attempt - in part - to explore the determinants of fixed-ratio performance. The focus of interest is not only upon schedules programmed with fixed trials. It is hoped that any provisional statements concerning control in a discrete-trials schedule would also be generalizable to free operant procedures. Here then is the essence of the problem. The very existence of a repeating response pattern implies some degree of within-cycle sequential dependency which acts to modify the character of subsequent responding. It must be assumed that the stimulus environment provided by the antecedent response (and/or time-correlated stimuli) constitute an important part of schedule control.

If these dependencies are destroyed through the introduction of extended interresponse times, then the essential character (pattern of control) of the schedule would undergo gross modification, even though the formal properties of the reinforcement rule were maintained. Research reported by Nevin (1967) may be taken as a case in point. This investigator reinforced simultaneous discriminations after a fixed number of trials or after a fixed number of correct responses (FR-5). The maximum duration of each trial was fixed at two seconds. If a response did not occur within this interval, the trial was terminated. All trials were followed by a six-second intertrial interval. The fixed-trial procedure may therefore be considered analogous to a fixed-interval schedule with limited hold. (Nevin, 1967, p. 252) Examination of the within-cycle response probabilities reveals two important points: a) both scheduling procedures controlled identical response patterns, and b) the common response pattern was not suggestive of either FR or FI scheduling[1].

The research previously reviewed suggests that a regular (and presumably discriminable) schedule of reinforcement delivery may exert substantial control over the pattern of within-cycle accuracy. Both fixed-ratio and fixed-interval schedules can be <u>described</u> in terms of a repeating sequential discrimination in which an S^{Δ} period is terminated

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[1] These results are consistent with data obtained in pilot work for the present experiment. Intertrial intervals of ten seconds were found to disrupt FR performance. Ratios larger than five could not be reliably maintained, and measures of within-cycle responding did not suggest the emergence of fixed-ratio control.

after a fixed time, or fixed number of responses; the subsequent S^D condition is then terminated with reinforcement delivery. If this point of view can be extended beyond the descriptive level, the within-cycle accuracy patterns maintained by both schedules might be understood as a joint product of two independent sources of stimulus control: the discriminative regularities of reinforcement delivery and the exteroceptive discrimination.

An investigation of this proposition can proceed in the same manner as the assessment of any instance of stimulus control. If a stimulus dimension which controls a performance is changed in value, then the behavior will change. Thus, if the within-cycle accuracy pattern is controlled by the regularities of reinforcement delivery, changes in the distribution of reinforcement (re time or responses) should produce a concomitant modification of the response pattern. This procedure therefore makes a distinction between control by reinforcement *per se*, and control by the specific regularities (temporal or otherwise) with which reinforcement is made available. The influence of the exteroceptive discrimination can be approached in the same general manner.

The present investigation constitutes an extension and a systematic replication of those previous investigations which have examined within-cycle patterns of response accuracy. Simultaneous brightness discriminations are maintained on FI and FR schedules of reinforcement.

Within-cycle effects on both schedules were examined as a function of both the difficulty of the discrimination (S−/S+ disparity) and the regularity of the maintaining schedule.

Method

Subjects

The subjects were eight male Charles Rivers Caesarian derived rats. The animals were 80-100 days old at the time of arrival at the laboratory. The animals were housed in individual cages and maintained *ad libitum* on both food and water for a period of three weeks. Food consisted of Purina Rat Mash. During the final week of this period, each animal was handled daily for a period of approximately 15-20 minutes. At the end of the three weeks, the animals were placed on a 23-hour food deprivation schedule. Water was continuously available. Handling was continued for all animals on alternate days until the start of the experimental procedures.

Apparatus

The experimental environments were two dual-lever rat chambers manufactured by Scientific Prototype Mfg. Co. The 25- x 30- x 20-cm chambers were enclosed in sound attenuating boxes provided with forced air ventilation and sound masking provided by a Grason Stadler Model 901B Noise Generator.

The two levers were mounted in the wall at one end of the test chamber with the top surfaces 4.4 cm above the grid floor. The portion of the levers within the cage was 7.5 cm wide and extended 1.9 cm from the cage wall. A displacement of approximately 0.6 cm and

and a force of 0.08 to 0.12 N was required to effect closure of the normally open contacts of the microswitches. The inside edges of the two levers were 7.8 cm apart. A 1.9- x 4.4- x 3.6-cm brass food cup was centered between the two levers with its top surface at the same elevation as the top surface of the levers.

Each chamber contained two stimulus displays. As viewed from the inside, each display appeared as an opaque white circle, 2.5 cm in diameter, mounted flush with the wall and centered 10.0 cm above the top surface of each lever. Each stimulus source consisted of a small two-channel mirror type tachistoscope. Each channel could be independently illuminated by a G.E. 24-volt, 6 A tungsten filament bulb. One channel was fitted with slide holders. Kodak No. 96 Wratten neutral density filters, mounted in Agfa 5- x 5-cm glass slide mounts, could be inserted to attenuate channel intensity. This arrangement provided an S- stimulus whose intensity could be systematically manipulated relative to the fixed value S+ stimulus provided by the second channel.

The intensity of all four stimuli (S+ and S- for both the right and left displays) were measured with a Macbeth Illuminometer.

Interval schedules were instrumented by allowing a six-second recycling timer to advance a stepper at the end of each time period. The duration of each cycle, whether fixed or variable, was some multiple of six seconds. The interval schedules were programmed with an unlimited hold. When the interval had been timed out, the timer was automatically stopped until a reinforced response occurred. Programming the ratio schedules differed only in that a predetermined class of response advanced the stepper.

Procedure

All conditioning sessions were conducted with the subjects 23 hours food deprived. Forty-five mg Noyes rat pellets were used for reinforcement. Training sessions were conducted six days a week with each animal being run at approximately the same time of day. Individual training sessions were continued until the animal had collected 65 reinforcements. Water was continuously available in the chambers.

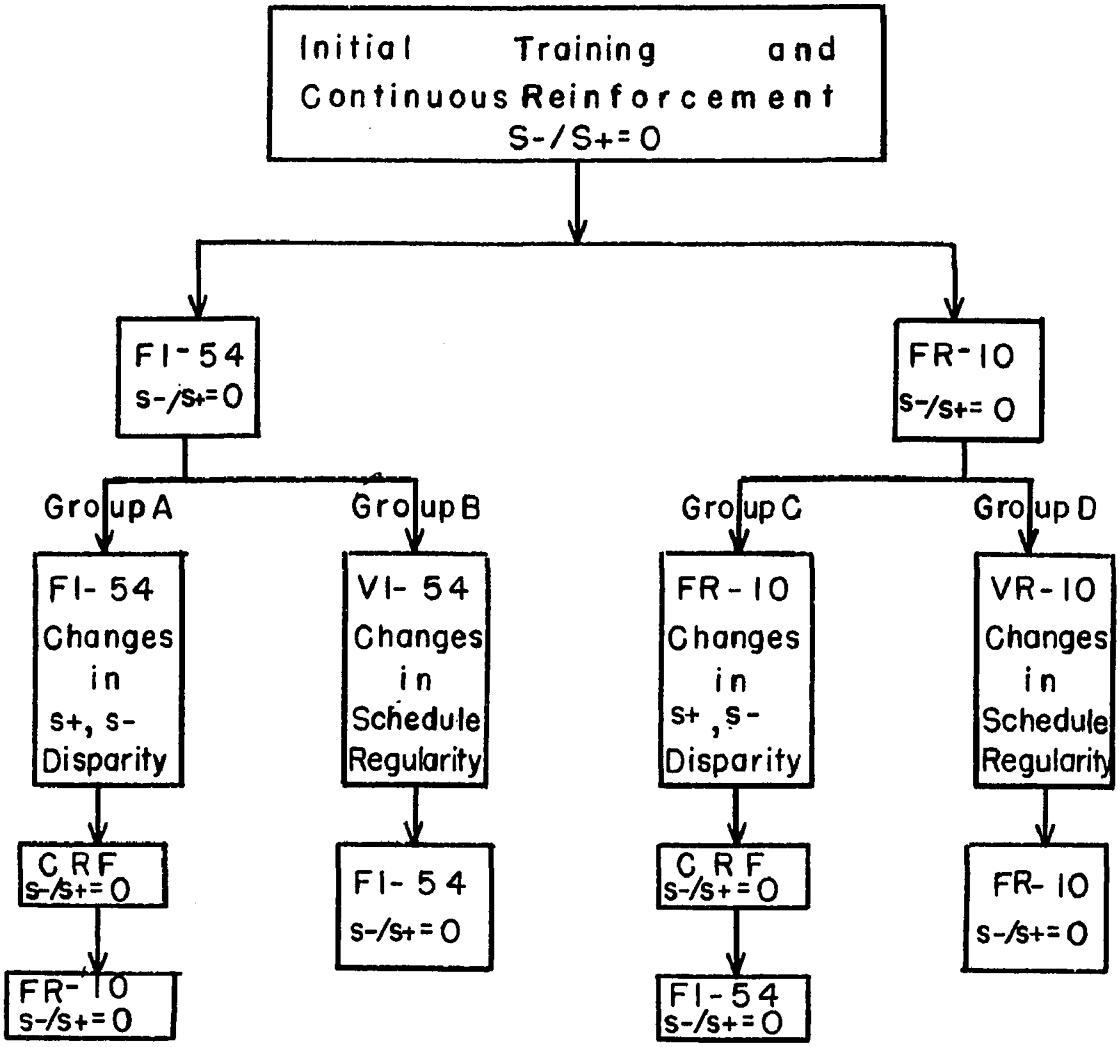
Following two weeks of the deprivation regime, training was initiated by placing a small amount of Purina Rat Mash in the food cup and introducing the food-deprived animal into the test environment. One S+ stimulus was illuminated, and the S- channel of the opposite display was illuminated. A response on the lever immediately under the S+ stimulus (S+ response) resulted in the automatic delivery of one 45 mg food pellet, while a response on the lever immediately under the unilluminated display (S- response) was not reinforced. S+ responses were followed by a 0.350-second intertrial interval, while S- responses were followed by a 0.600-second intertrial interval. During intertrial intervals the stimulus lamps were not illuminated and all responses restarted the operating timer, postponing the start of the next trial and insuring a minimum period of non-response between each trial. The termination of the intertrial interval started a new trial. The position (right or left) of the positive stimulus (S+) was selected at random for each trial, with each position having a 0.50 probability. All animals were allowed to acquire the lever-press response without further intervention by the experimenter.

When informal observation made it apparent that the average latency from the onset of a new trial to response had fallen below one second, the intertrial interval following an S- response was shifted from 0.6 to 6.0 seconds. All animals were run on the following procedure: Continuous reinforcement (CRF) for responses to the bar associated with S+. This was continued six days a week until the overall percentage of S+ response $\left(\frac{\text{S+ responses}}{\text{All responses}}\right)$ was 0.85 or better for five consecutive days. When the CRF criterion had been satisfied, the animals were moved into the first experimental condition. The overall experimental design is summarized in Table 1. Following CRF, one half of the animals (Rats 18, 21, 14 and 15) were placed on a 54-second fixed-interval schedule (FI-54) of reinforcement with the first S+ response occurring after 54 seconds producing reinforcement.

Responses occuring during the interval had effect only in initiating appropriate time outs. Intertrial interval durations and the fixed interval durations were timed independently. Therefore, if the

TABLE I

Sequence Of Experimental Conditions



Note.— Stimulus conditions are stated in terms of relative intensity of S- stimulus. A "0" ratio indicates an unilluminated S- display.

FI-54 were to terminate during an intertrial interval, this condition would override, and reinforcement would become available after the end of the intertrial interval.

The second group of four animals (Rats 23, 30, 31 and 32) were placed on a FR schedule with only S+ responses advancing the ratio count. Every tenth correct response was reinforced. The values of the intertrial interval for both groups of animals (0.350 seconds for S+ responses and 6.0 seconds for S- responses) were the same as those in the CRF condition.

Following exposure to the basic FR and FI schedules, each group was again divided into two subgroups. In the first subset, (Table 1, Groups A & C), S+, S- disparity was manipulated by progressively increasing the brightness of the S-. In the second subset, (Table 1, Groups B & D), the defining parameters of the schedule were manipulated by changing the amount of time (interval schedules) or number of responses (ratio schedules) required before reinforcement was available. The procedure provided a series of fixed and variable schedules with the same mean value in which several ranges of variation were explored.

<u>Changes in S-, S+ disparity.</u> The effects of discrimination difficulty upon performance in both fixed ratio and fixed interval were investigated by moving each animal through four additional levels of S+, S- disparity specified in terms of the relative intensity of the S-

stimulus. The measured brightness of the S+ and S- stimuli in each discriminative condition have been shown in Table 2. The indicated values represent the means of twenty separate measurements of each stimulus.

After data had been taken at the final level of brightness disparity, both FR and FI animals were returned to CRF with a S-/S+ ratio of zero. Training was continued until 85% of all responses were to the S+. When this criterion had been maintained for three consecutive days, the two animals previously maintained on a FR were placed on a FI-54 schedule and the FI animals were shifted to a FR of 10.

Changes in schedule regularity. The regularity of reinforcement availability was also varied independently in both interval and ratio schedules. This procedure involved phasing the FR-10 into a VR-10 and the FI-54 into a VI-54 by increasing the variability about a constant mean ratio or interval in three predetermined steps. Within either type of variable schedule, different ranges of variability around the mean value were employed. These ranges were 3, 9, or 19 responses for the VR schedules, and a like number of six-second periods for the VI schedules. Thus, for the least variable VR-10, reinforcement occurred after either 9, 10, or 11 correct responses, while on the most variable VR-10, from 1 to 19 correct responses might be required for reinforcement. On the most variable VI-54 schedules, from 1 to 19 six-second periods might elapse before reinforcement eligibility was established. With all of the variable schedules, equal probability of reinforcement was main-

TABLE 2

Discrimination Ratios

Discrimination Conditions[a]	Brightness (candle/m^2)					
	Ratio Animal			Interval Animal		
	S+	S-	S-/S+	S+	S-	S-/S+
1	46.0	0.0	.00	51.0	0.0	.00
2	47.3	1.7	.04	51.5	2.0	.04
3	42.5	7.2	.17	57.8	8.8	.15
4	44.5	15.0	.33	47.2	13.3	.28
5	41.5	26.8	.64	45.5	28.0	.61

[a] In order of presentation.

tained across the range of variation. Table 3 shows the scheme of these schedules along with the percentage of reinforcement which became available at all schedule locations. For convenience of schedule specification, each schedule is identified by the average deviation (AD) of programmed reinforcements relative to either time or responses.

The criterion for stable performance in all experimental conditions was as follows: First, a minimum number of training days were required. Beyond the specified minimum, performance was considered stable when there was no identifiable[2] trend in the percent of S+ responses. When FI schedules were employed, a similar criterion for stability was imposed on the mean number of responses in each FI cycle. When both criteria had been satisfied, performance was considered stable and final data was taken over a period of five additional days. In all experimental conditions, the first 15 cycles occurring on each of the five days was dropped from the data analysis. The total data sample was therefore 250 cycles, 50 cycles per day for five days.

The minimum number of training days required for each experimental condition, along with the actual number of training days for each condition, is shown in Table 4 for animals for which the discriminative

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2. The procedure involved visual inspection of the data rather than statistical comparison with a predetermined criterion. If the sign of the difference between a 5-day moving average and the daily percent correct appeared to be randomly distributed over the final six days, then the data was accepted as stable.

TABLE 3

Specification Of Variable Schedules

Nth 6 Sec. Time Period Nth S+ Response	Percentage of Reinforcements			
	Fixed Schedules	First Variable Schedule	Second Variable Schedule	Third Variable Schedule
1				5.0
2				5.3
3				5.3
4				5.3
5				5.3
6			11.1	5.3
7			11.1	5.3
8			11.1	5.3
9		33.3	11.1	5.3
10	100	33.4	11.1	5.2
11		33.3	11.1	5.3
12			11.1	5.3
13			11.1	5.3
14			11.1	5.3
15				5.3
16				5.3
17				5.3
18				5.3
19				5.0
Average Deviation				
in Responses	0	.67	2.2	4.7
in Seconds	0	4.0	13.2	28.2

condition was varied, and in Table 5 for those animals subjected to changes in schedule variability.

Data analysis of the interval schedules included measures of performance in each successive six-second segment of the interval. Analysis of the ratio schedules was based upon successive positions in the response sequence. The first ratio position, for example, includes data from all measured behavior occurring from the previous reinforcement up to and including the first S+ response. Similarly, the second position includes all measurements taken after the termination of the first S+ response up to and including the second S+ response.

Data was taken separately for each response on a Presin printing counter. The following data was obtained under all experimental conditions.

<u>Cumulative Response Latency.</u> The time between the termination of any time out and the response. The data is cumulative for all responses (S+ or S-) over the complete cycle. The initial latency of each cycle is measured from the termination of the 350 msec which followed reinforcement, the reinforced response necessarily being an S+ response.

<u>Response Identification.</u> The identification of the response as having been on the lever associated with the S+ or the S-.

TABLE 4

Days of Training for Animals Exposed to Changes in S+, S- Disparity

Schedule Condition	Descrimination Ratio S- / S+	Number of Training Days				
		Minimum Required	ACTUAL			
			Rat 18[a]	Rat 21[a]	Rat 23[b]	Rat 30[b]
CRF	.000	None	15	18	22	17
FI-FR	.000	20	30	36	32	27
FI-FR	.060	10	16	14	16	15
FI-FR	.160	10	17	16	19	19
FI-FR	.310	10	19	18	15	17
FI-FR	.625	10	11	10	12	14
CRF	.000	5	5	10	12	18
FR-FI	.000	20	26	18	31	24

[a] Fixed Interval Animals.

[b] Fixed Ratio Animals.

TABLE 5

Days of Training for Animals Exposed to Changes in Schedule Regularity

Schedule Condition	Number of Training Days				
	Required	Actual			
		Rat 14[a]	Rat 15[a]	Rat 31[b]	Rat 32[b]
CRF	None	26	28	16	17
FI-FR	20	28	25	20	29
First Variable Schedule	15	19	22	26	18
Second Variable Schedule	15	17	15	17	23
Third Variable Schedule	15	22	21	21	16
FI-FR	15	21	20	22	14

Note.– $s-/s+ = 0$ for all data.

[a] Interval Animals.

[b] Ratio Animals.

Response Position. In FR, the identification of the serial position of the response within the series of unreinforced responses which constitute the ratio. In FI, the identification of the response as occurring within any given six-second part of the interval.

Reinforcement. The identification of a response as having been reinforced or not.

Results

The Ratio Schedules

<u>Baseline Performance</u> (Rats 23, 30, 31 and 32)

The cumulative median latency of the ten responses[3] which constitute the ratio are shown in Figure 1. The curves are median representations of the 250 individual fixed-ratio cycles, which were derived from the final five days of initial FR training. The medians were plotted as a function of schedule "time in", in which zero time started at the end of the 0.350-second time out which followed the preceding reinforced response. In this condition, S-/S+ was zero, indicating maximum stimulus disparity.

For three of the four animals (Rats 23, 31 and 32), the initial response latency was of short duration. This was followed by the

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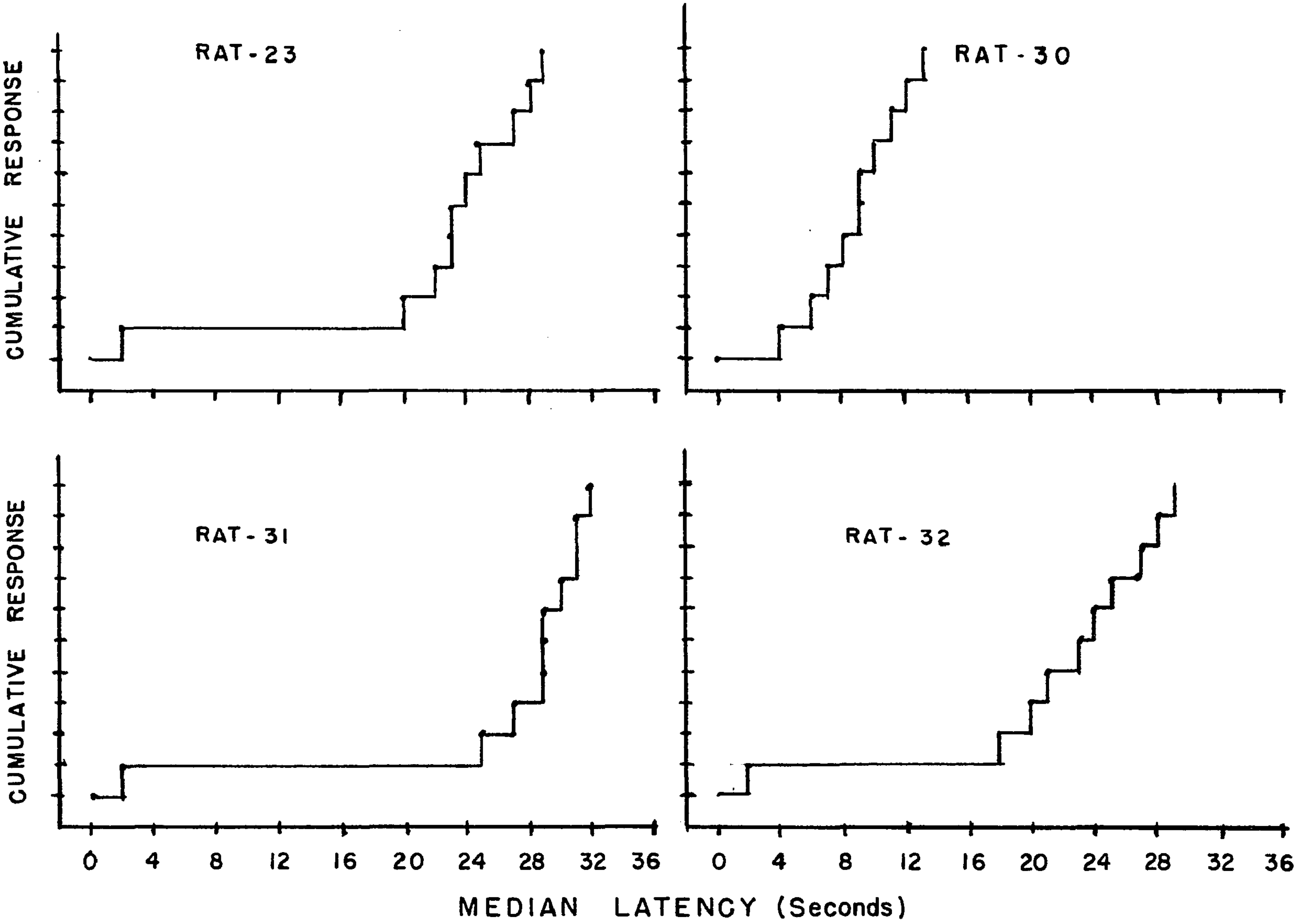
[3] These curves reflect only correct responses. Error (S-) latencies were deleted to preserve a uniform 10-step ratio. It is important to note that inclusion of the small population of S- latencies would not produce noticeable changes in the plotted medians.

Figure 1. The cumulative median latency for each of the ten S+ responses which constitute the fixed ratio. The curves effectively provide a median cumulative response record expressed as a single fixed-ratio cycle. S-/S+ = 0, and AD = 0 for all four animals.


RAT-23
RAT-30
RAT-31
RAT-32
CUMULATIVE RESPONSE
CUMULATIVE RESPONSE
0
4
8
12
16
20
24
28
32
36
MEDIAN LATENCY (Seconds)

longest median latency which occurred between the first and second responses. For Rat 30, the first and longest response latencies were coincident. Starting with the second response, however, all four subjects showed rapid transition to a relatively high rate. The final eight responses were completed in from 7.0 to 11.0 seconds.

Within-cycle accuracy for progressive thirds of the ratio was shown in Fig. 2 for the four animals exposed to the ratio contingency. Here the proportion $\left(\frac{\text{S+ responses}}{\text{All responses}}\right)$ of correct (S+) responding was plotted as a function of thirds of the ratio. The sample was again 250 cycles for each subject. The first data point (Cycle Positions 1 to 3) for each animal was therefore derived from a population of 750 correct responses plus the sum of all error responses which occurred prior to the third correct response. The initial shift from CRF (S-/S+ = 0) to the first FR schedule (S-/S+ = 0) produced a small (about 10%) overall accuracy decrement for all four subjects. For three of the four animals, there was also a small but regular accuracy decrement across progressive thirds of the ratio. This decline in accuracy was not large in absolute terms, but it was statistically reliable beyond the .01 level of confidence.[4] For Rat 23, there were no identifiable within-cycle changes.

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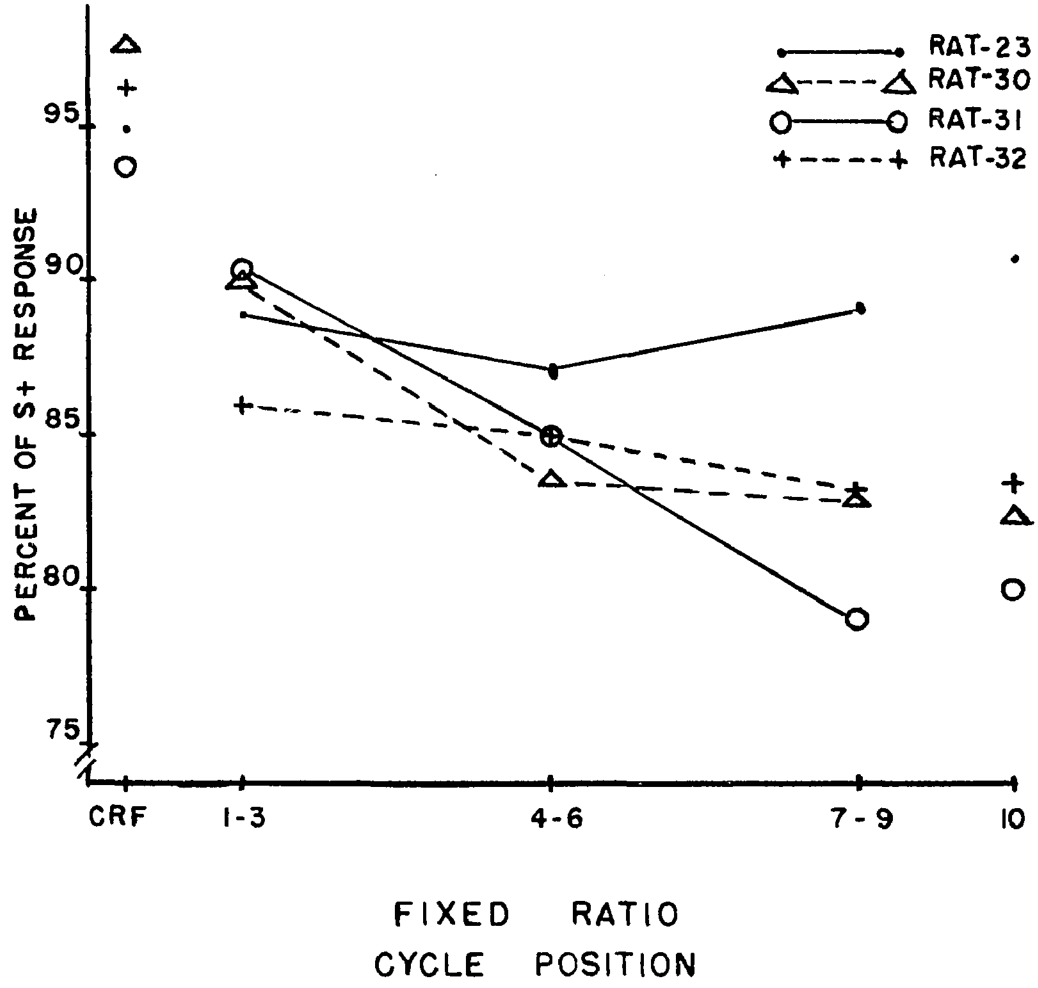
4. Chi square one sample test; df = 2, χ^2 = 12.9, 43.6 and 50.3

Figure 2. Percentage of S+ response as a function of progressive thirds of the fixed ratio. Overall proportion of S+ response under the CRF condition is shown on the left. S-/S+ = 0 for all data.


RAT-23
RAT-30
RAT-31
RAT-32
95
90
85
80
75
PERCENT OF S+ RESPONSE
CRF
1-3
4-6
7-9
10
FIXED RATIO
CYCLE POSITION

Although the expected within-cycle accuracy pattern was not observed, a substantial relation between accuracy of the first response of a cycle and the latency of that response was evident. The relative frequency of S+ responses $\left(\frac{S+}{S+,\ S-}\right)$ for the population of first responses after reinforcement has been shown in Figure 3 as a function of the time since the previous reinforced response. Correct and error frequencies were summed over all 250 cycles, and percent correct figures were derived from these totals. The relative frequency of post-reinforcement pauses terminated by an S+ response was an increasing, negatively accelerating function of latency.

For three of the four animals (Rats 23, 30 and 32), the initial 18 seconds after reinforcement were associated with an accuracy decrement which reduced the percentage of S+ responding substantially below the level maintained under CRF. At longer latencies, the situation has reversed itself. Not only has CRF accuracy been exceeded, but for the three animals under consideration, there was no S- responding at all. It is evident that the exclusive S+ responding observed at latencies in excess of 36 seconds was based upon a very small sample. In point of fact, this response class contained somewhat fewer than 30 occurrences[5] for all three animals. However, this does not appear to be due to chance: The temporal properties of the schedules have

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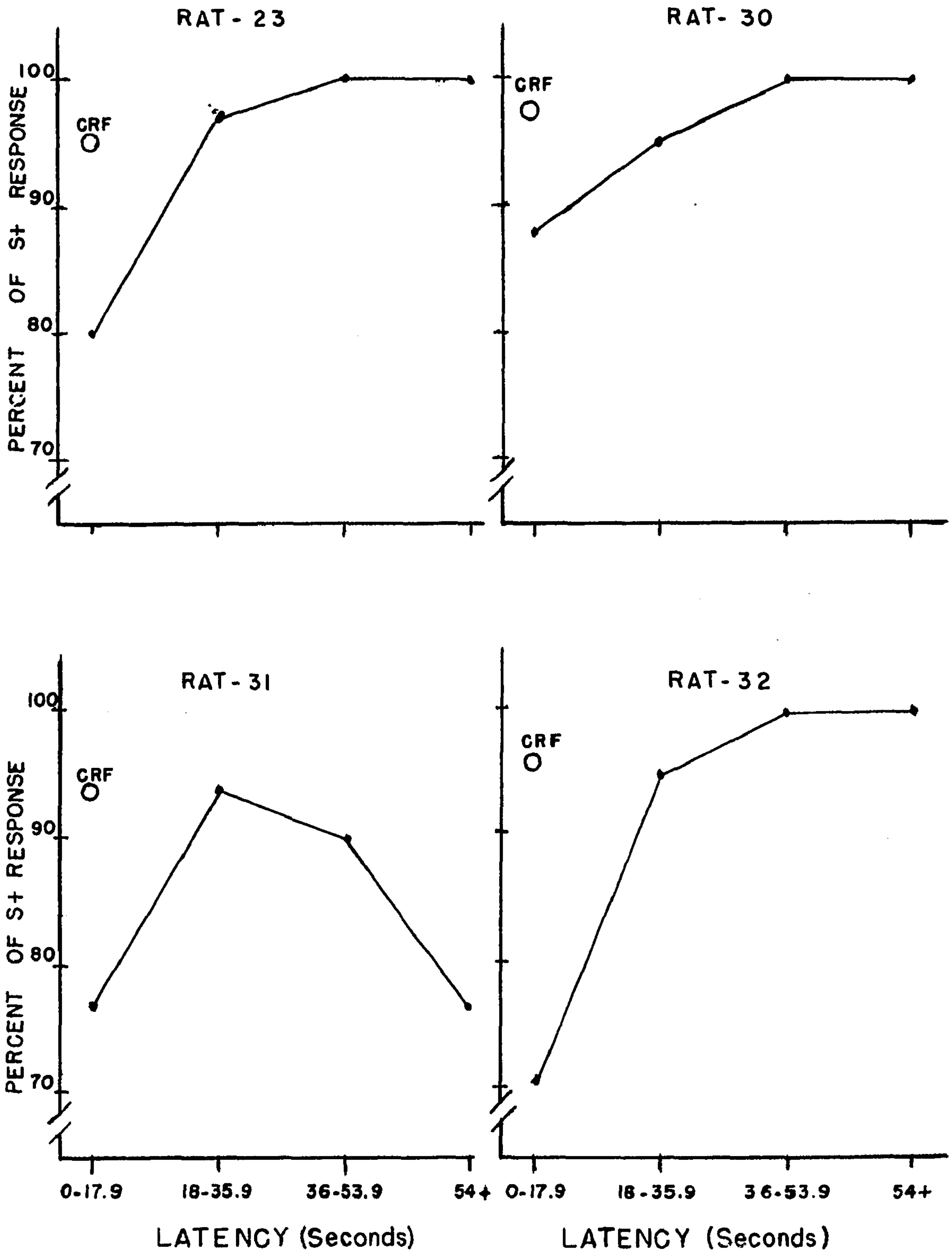
[5] For Rat 23, n = 23; Rat 30, n = 12; Rat 32, n = 6.

Figure 3. Proportion of first responses occurring to the S+ as a function of latency. The data are for the FR-10, with S-/S+ = 0. Proportion of total responses occurring to the S+ during CRF is shown as a single unconnected point at the left.


RAT- 23
RAT- 30
RAT- 31
RAT- 32
PERCENT OF S+ RESPONSE
100
90
80
70
CRF
0-17.9
18-35.9
36-53.9
54+
LATENCY (Seconds)

exerted sufficient control over S+ responding to permit the appearance of accuracy levels substantially greater than those observed under CRF. The data for Rat 31 are in only partial conformity with this trend. The inverted U function suggests maximum accuracy at a temporal location which is coincident with initiation of the uninterrupted response sequence (cf. Figure 1).

Changes in Discrimination Ratio (Rats 23 and 30)

Changes in the overall percentage of S+ responding which were induced by the several values of S-, S+ disparity were shown in Table 6. A systematic decrease in accuracy was apparent for both animals. These changes in overall accuracy were not, however, accompanied by modification of the within-cycle accuracy pattern (Figure 4). The functions displaced uniformly downward and were without distinct within-cycle changes. As in Figure 2, there was a tendency toward lowered accuracy in the final portions of the cycle. In six of the ten functions shown, the percentage of S+ responding was greater in the first third of the cycle than in the last, but the differences were typically quite small. Sharply articulated accuracy of first response functions (Figure 5) of the type observed in the basic ratio schedules were maintained, even though changes in the S-/S+ ratio reduced overall accuracy to near chance levels. Differential effects related to changes in discrimination ratio appeared primarily for the shorter latencies,

TABLE 6

Proportion of Total FR Responses Made to the Lever Associated with the S+ as a Function of Discrimination Ratio

S- / S+	Percent S+ Response	
	Rat 23	Rat 30
0[a]	.89	.95
.04	.83	.79
.17	.83	.70
.33	.73	.58
.64	.62	.49

[a] Indicates unilluminated S- display.

Figure 4. Proportion of total responses to the S+ as a function of successive thirds of the FR-10 for all five values of S−/S+. Data for the final ratio position is shown as a disconnected point at the right.

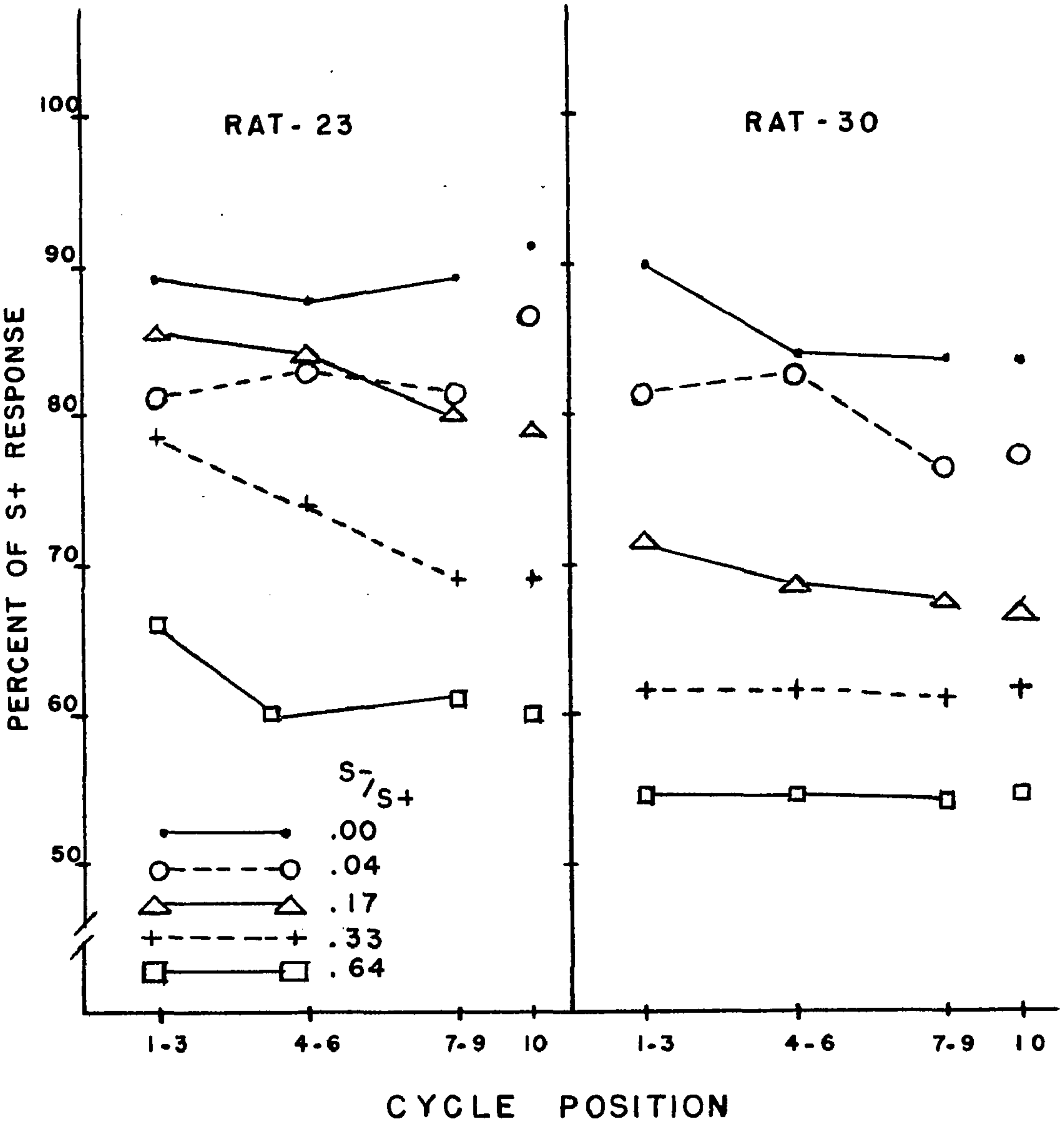
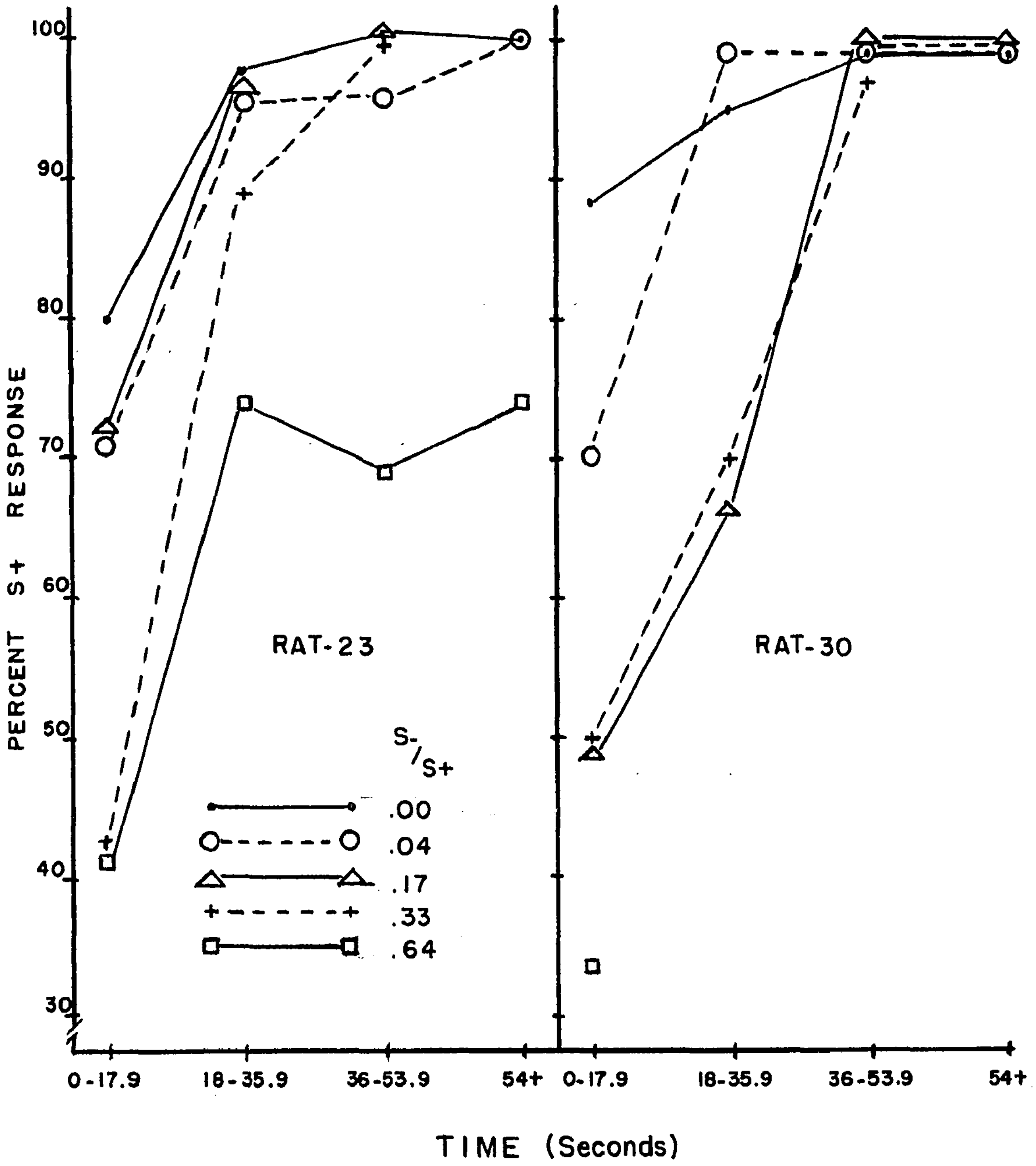

RAT - 23
RAT - 30
PERCENT OF S+ RESPONSE
100
90
80
70
60
50
S-/S+
.00
.04
.17
.33
.64
1-3
4-6
7-9
10
1-3
4-6
7-9
10
CYCLE POSITION

Figure 5. Proportion of total first responses to the lever associated with the S+ as a function of latency. The data are for the FR-10 schedule at all five values of S-/S+. Vacant data points (for example, Rat 30, S-/S+ = .64) indicate an absence of responding at that temporal location.


PERCENT S+ RESPONSE
100
90
80
70
60
50
40
30
RAT-23
RAT-30
S-/S+
.00
.04
.17
.33
.64
0-17.9
18-35.9
36-53.9
54+
0-17.9
18-35.9
36-53.9
54+
TIME (Seconds)

while latencies in excess of 36 seconds were correlated with almost perfect accuracy at all but the greatest S-/S+ values. Of course, these populations of long latency responses were quite small, comprising an average of 8 occurrences per S-/S+ value for Rat 30, and 20 occurrences per S-/S+ value for Rat 23. However, the reliably accurate behavior with long latency was clearly distinct from shorter latency responding. Post-reinforcement pause duration showed no systematic relationship to the discrimination ratio. This population of median latencies has been summarized in Table 7. In all cases, the medians were derived directly from the total population of latencies.

Changes in Schedule Variability (Rats 31 and 32)

The overall percentage of S+ responding maintained by the several levels of ratio schedule variability was shown in Table 8. Rat 31 showed a slight tendency toward reduced accuracy with increased schedule variability. Each increase in AD was accompanied by a uniform 2% decrease in accuracy. The data for Rat 32 showed accuracy changes as large as 5% between experimental conditions, but there was no discernible relationship between schedule variability and accuracy. It is evident that ratio schedule variation did not exert meaningful control over percent of S+ responding.

The median first response latency (post-reinforcement pause) characteristic of each fixed- and variable-ratio performance was shown

TABLE 7

Median FR Postrienforcement Pause as a Function of Discrimination Ratio

S- / S+	Median Postreinforcement Pause (Seconds)	
	Rat 23	Rat 30
.0[a]	1.5	4.0
.04	3.5	1.5
.17	21.5	2.5
.33	20.0	1.5
.64	4.0	1.5

[a] Indicates an Unilluminated S- Display.

TABLE 8

Proportion of Total Responses to The Lever Associated With the S+ as a Function of Ratio Schedule Deviation

Average Deviation	Percent S+ Response	
	Rat 31	Rat 32
0[a]	.83	.84
.67	.81	.88
2.20	.79	.89
4.70	.77	.84

Note.- S−/S+ = 0 for all data.

[a] Fixed ratio.

in Table 9. It is clear that changes in AD acted to modify the uniformly short pauses only at the schedule of greatest variability. The small differences between the fixed-ratio (AD = 0) figures and analogous data from Figure 1 resulted from the inclusion of S- responding in the tabled medians.

In Figure 6, the relative frequency of S+ response was shown as a function of cycle position for the three variable schedules. The basic fixed-ratio (AD = 0) accuracy data was reproduced for comparison. The cycle position makes reference to all responding made to advance the ratio a single step. For example, the third cycle position would include the third correct response plus any error responding intervening between the second and third correct response. Each panel in Figure 6 reflects the combined performance for five days under that particular experimental condition. Percent of S+ responding $\left(\frac{S+}{S+,\ S-}\right)$ was derived from total frequencies. It should be noted that the number of observations systematically decreased across cycle positions for the variable schedules. For each schedule 250 observations were involved for Position 1 of the ratio. The smallest sample was 12 for the final position of the ratio of greatest variability (Position 19, VR-10, AD = 4.7). The N for all positions of each schedule may be derived with reference to Table 3.

The small decline in percentage of S+ responses as the ratio was counted out has been previously noted. The data for Rat 31 were somewhat less clear-cut than that for Rat 32, but the general effect was

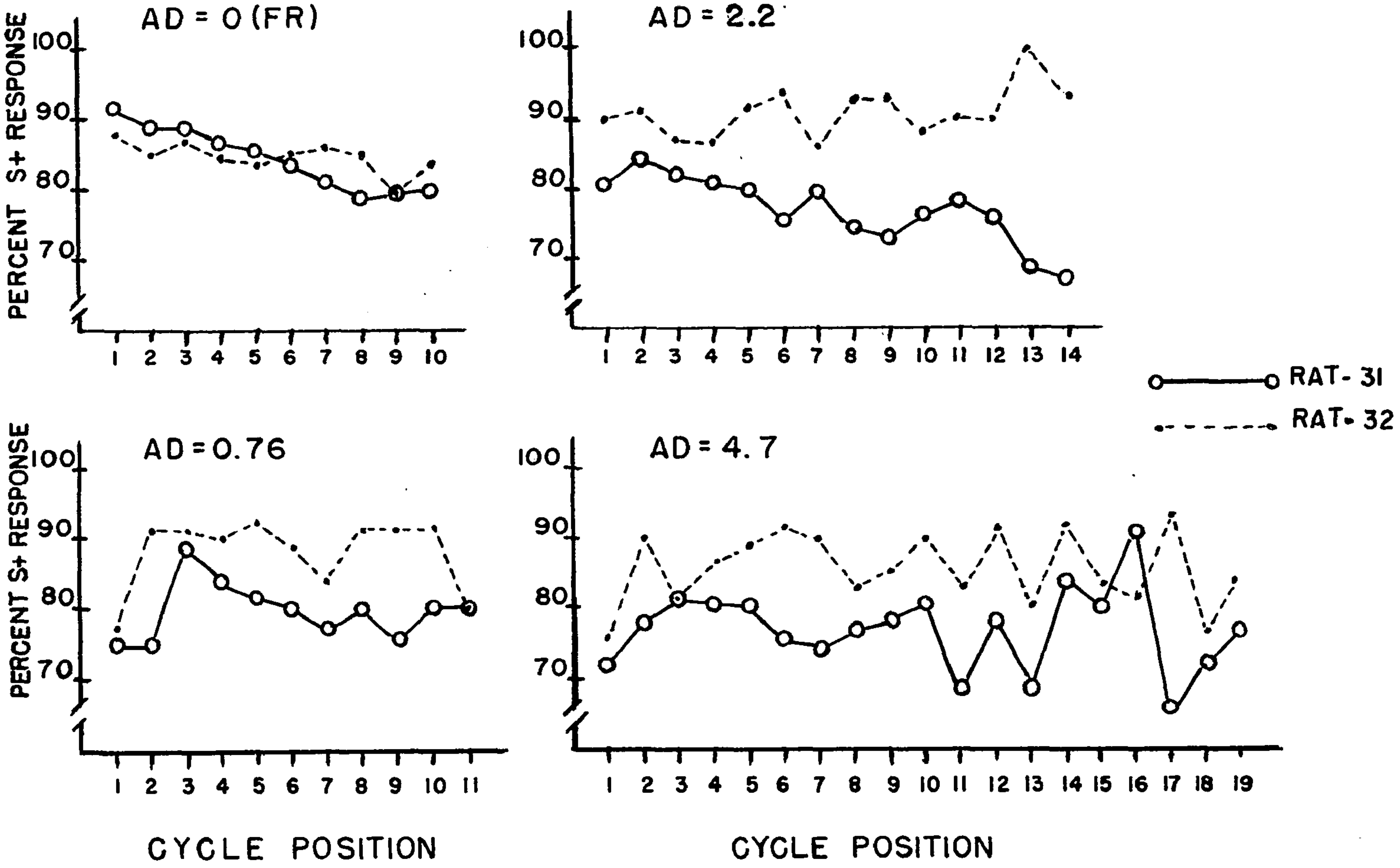
TABLE 9

Median Postreinforcement Pause as a Function of Average Deviation of the Ratio Schedule

Average Deviation	Median Postreinforcement Pause (Seconds)	
	Rat 31	Rat 32
0[a]	2.0	1.5
.67	2.0	1.5
2.20	2.0	1.5
4.70	1.0	0.5

[a] Fixed Ratio.

Figure 6. Proportion of total responses to the S+ as a function of ratio cycle position for the fixed value schedule as well as the three VR schedules. S-/S+ = 0 for all data.

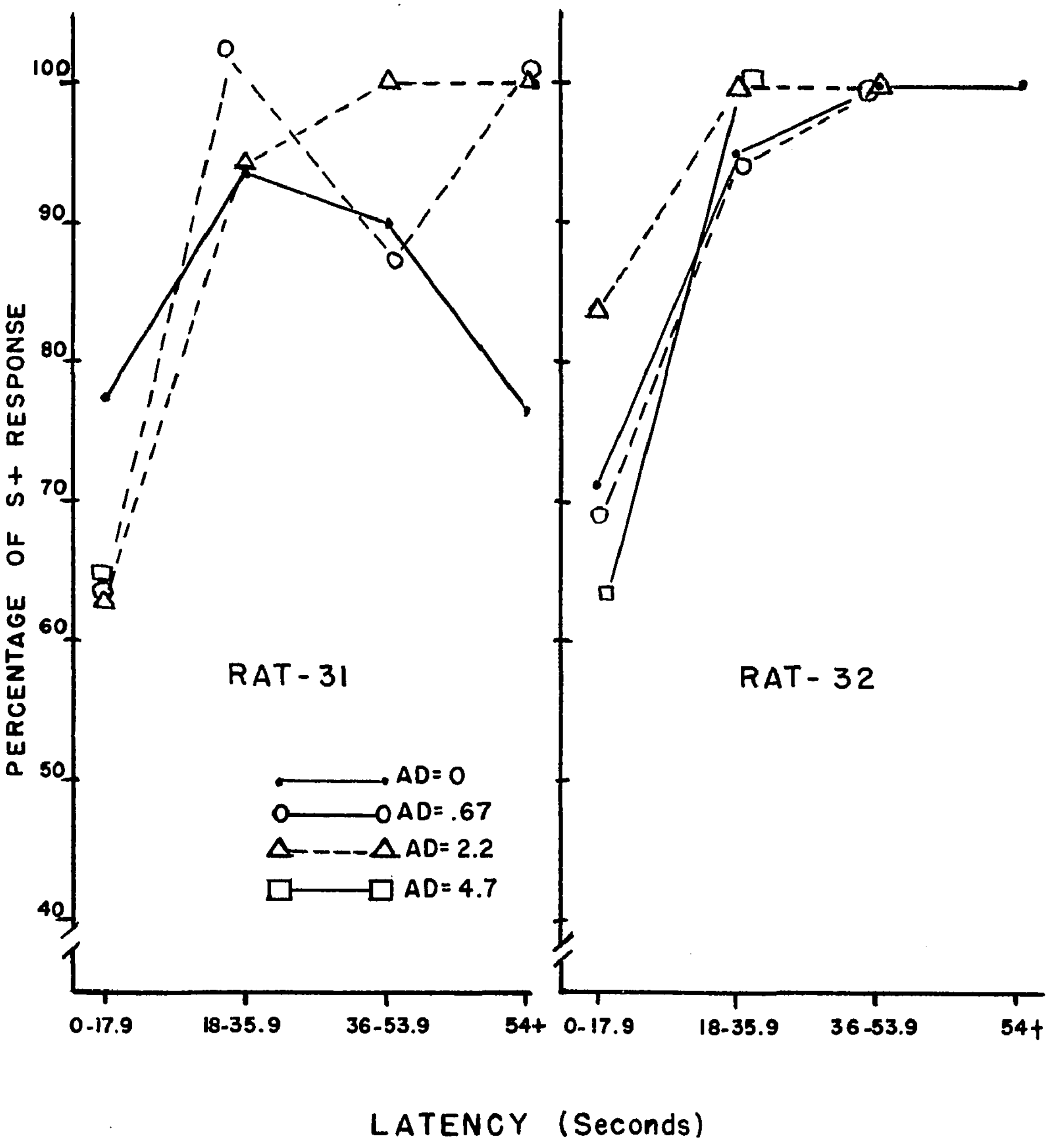

AD = 0 (FR)
AD = 2.2
AD = 0.76
AD = 4.7
PERCENT S+ RESPONSE
PERCENT S+ RESPONSE
100
90
80
70
1 2 3 4 5 6 7 8 9 10
1 2 3 4 5 6 7 8 9 10 11 12 13 14
1 2 3 4 5 6 7 8 9 10 11
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
CYCLE POSITION
CYCLE POSITION
RAT- 31
RAT- 32

consistent with previous FR accuracy patterns (Figure 2). For the three variable ratio schedules, Rat 31 continued to show a slight tendency for the curve to fall off as the ratio was counted out, while the curves for Rat 32 remained essentially flat throughout.

The accuracy of responding which terminated the post-reinforcement pause has been shown as a function of latency in Figure 7. This figure reproduced the initial FR data (Figure 3) along with the data for the three variable ratio schedules. For Rat 32, the accuracy functions first observed in the basic FR data did not exhibit systematic modification as AD was increased. The inverted U-shaped curve obtained in the FR condition for Rat 31 appeared to have undergone progressive modification toward the typical increasing negatively accelerating function produced by the schedule of intermediate variability (AD = 2.2). For both animals, the reduced number of data points for the schedule of greatest variability (AD = 4.7) reflected the reduced PRP duration previously noted in Table 9. After exposure to the schedule of greatest variability, Rats 31 and 32 were returned to the basic FR schedule. This redetermination produced data which were in all major respects identical to that observed initially.

In summary. Changes in discrimination ratio and schedule variability have not produced substantive changes in the distribution of within-cycle S+ responding. In both cases the data are wholly predictable from an examination of the basic FR (S-/S+ = 0, AD = 0) response pattern.

Figure 7. The proportion of total first responses to the lever associated with the S+ is shown as a function of latency for the FR-10 (AD = 0) as well as for the three VR schedules. Vacant data points indicate an absence of responding at that temporal location. S-/S+ = 0 for all data.


PERCENTAGE OF S+ RESPONSE
100
90
80
70
60
50
40
RAT-31
RAT-32
AD= 0
AD= .67
AD= 2.2
AD= 4.7
0-17.9
18-35.9
36-53.9
54+
0-17.9
18-35.9
36-53.9
54+
LATENCY (Seconds)

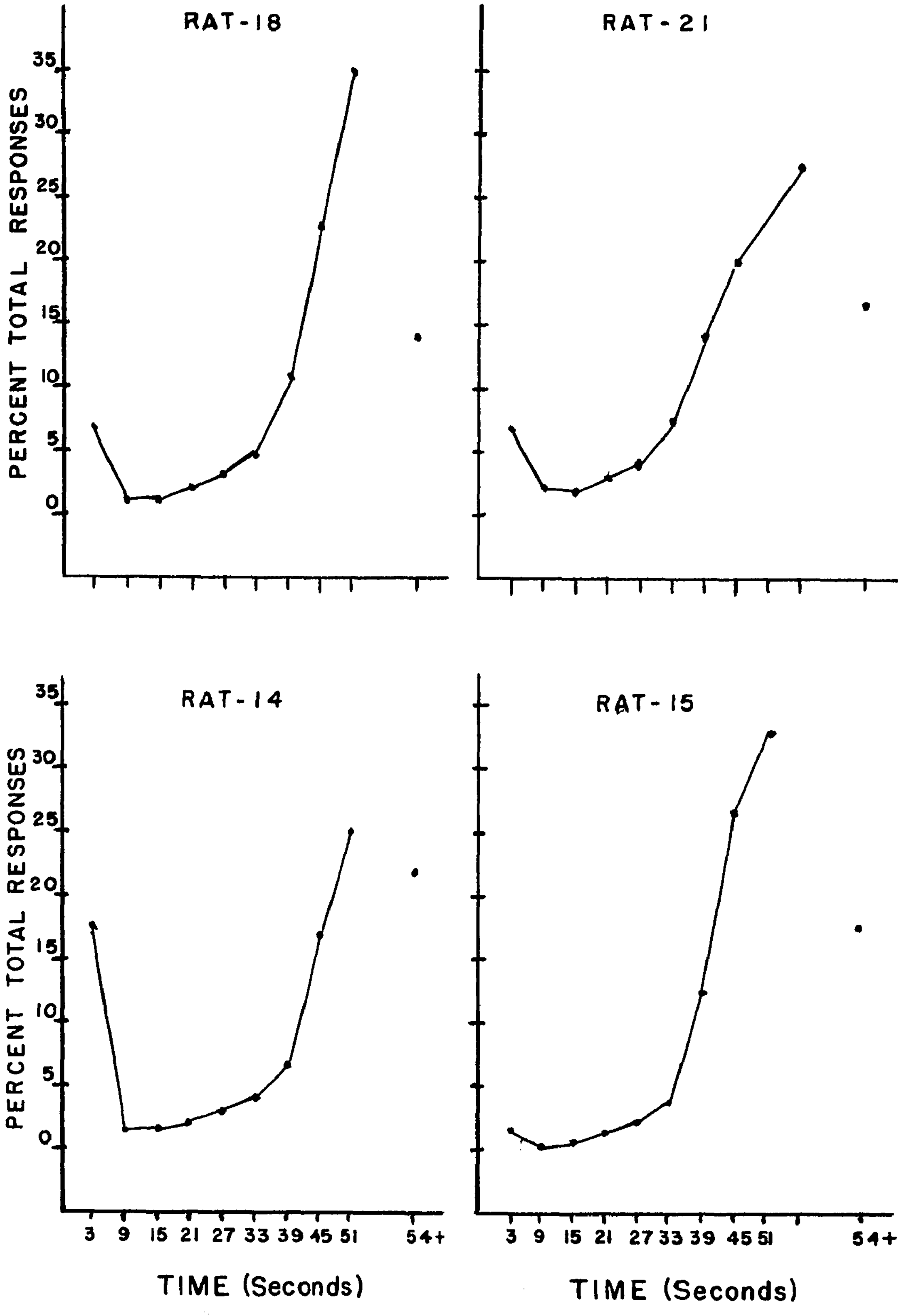
Strong schedule control over local accuracy was, however, shown in the relation between the latency and accuracy of the first response. At temporal locations remote from the preceding reinforcement, schedule control was strong enough to maintain accuracy at levels above CRF values. This strong temporal control was not disrupted by changes in schedule variability or - more importantly - changes in the discrimination ratio.

The Interval Schedules

Baseline Performance (Rats 14, 15, 18 and 21)

The pattern of responding produced by the FI schedule has been shown in Figure 8. These data represent the final five days' performance under this condition during which a total of 250 FI cycles were observed for each animal. The curves show the percentage of total responses occurring in each successive six-second segment of the 54-second interval. There was considerable similarity in the general shape of the curves for all four subjects. Three of the four exhibited relatively high response percentages within the first six seconds; in the most extreme case (Rat 14), 17.5 percent of all responses occurred during this period. After this initial "burst" of responding, the percentage of responses for all subjects decreased sharply in the subsequent six-second period and then increased systematically across the interval. Between 26.0 percent (Rat 14) and 35.0 percent (Rat 18) of all

Figure 8. Percentage of total responses (S+ and S-) occurring in each six-second segment of the fixed-interval schedule. The curves effectively provide an average response record expressed as a single fixed-interval cycle. Responses which occurred during reinforcement availability are shown as unconnected points on the right. S-/S+ = 0 for all data.


RAT-18
RAT-21
RAT-14
RAT-15
PERCENT TOTAL RESPONSES
0
5
10
15
20
25
30
35
3 9 15 21 27 33 39 45 51 54+
TIME (Seconds)

responding occurred in the six seconds prior to reinforcement eligibility. Inasmuch as the duration of this period was dependent upon the latency of the first S+ response, data for the period of reinforcement eligibility (in excess of 54 seconds) has been shown as an unconnected point on the right. All other points were plotted for periods of equal duration.

The likelihood that a given response would be to the lever associated with the S+ stimulus was found to vary systematically with time of occurrence within the 54-second fixed interval. The percentage of S+ responding occurring in each third of the basic FI schedule has been shown in Figure 9. Accuracy during the period of reinforcement eligibility was shown as an unconnected point on the right. The data demonstrated a systematic increase in relative frequency of S+ responding across successive thirds of the interval. The slight reversal which occurred in the final third of the interval for Rat 15 does not substantially contradict the general pattern. When compared with CRF accuracy levels, it was evident that this schedule-induced gradient resulted primarily from a sharp reduction in accuracy in approximately the first 18 seconds of the interval. Accuracy levels attained after 36 seconds were equal to or slightly exceeded those attained during CRF.

The likelihood that the first response of the FI cycle will be to the S+ has been shown as a function of latency in Figure 10. These data for the population of first responses were, in most important

Figure 9. Proportion of total responses to the lever associated with the S+ as a function of successive thirds of the fixed interval. Data from periods of reinforcement availability are shown as unconnected points on the right. The proportion of total S+ responses occurring during CRF training is shown as an open circle at the left. S-/S+ = 0 for all data.

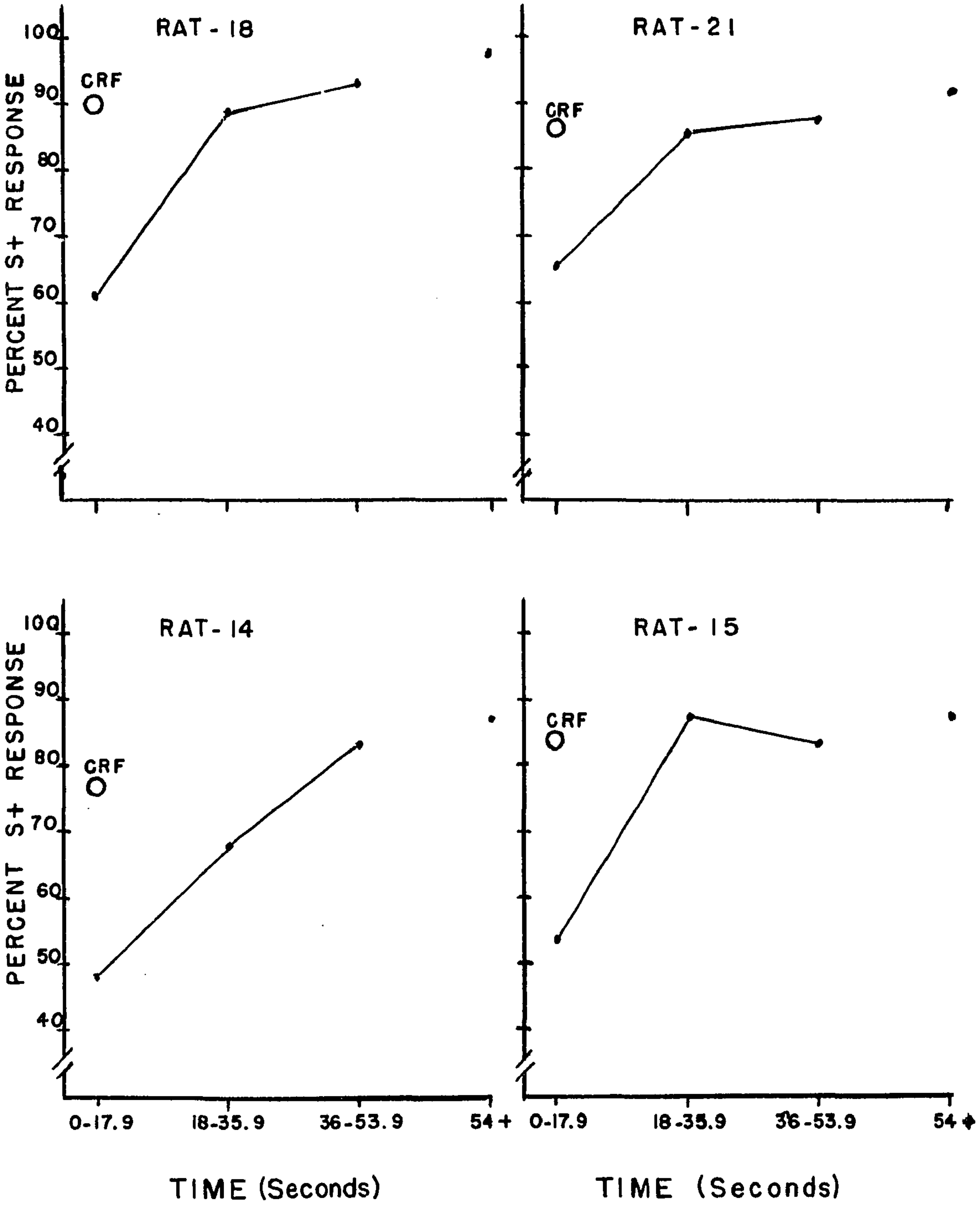
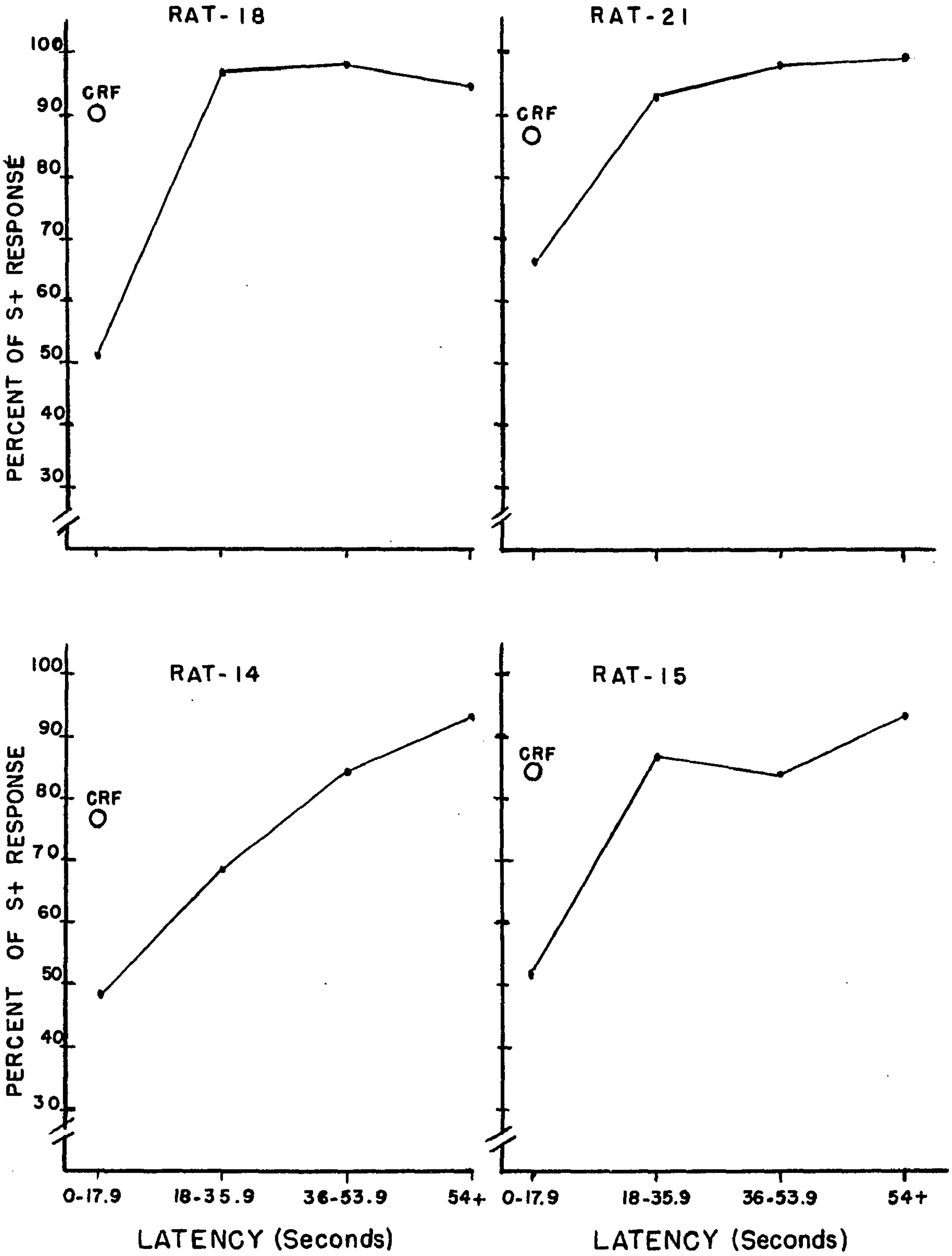

RAT-18
RAT-21
RAT-14
RAT-15
PERCENT S+ RESPONSE
PERCENT S+ RESPONSE
100
90
80
70
60
50
40
CRF
0-17.9
18-35.9
36-53.9
54+
TIME (Seconds)
TIME (Seconds)

Figure 10. Proportion of total first responses to the lever associated with the S+ as a function of latency. The data are for the fixed-interval schedule with S-/S+ = 0. Data from the CRF condition is shown as an unconnected point on the left.


RAT-18
RAT-21
RAT-14
RAT-15
CRF
PERCENT OF S+ RESPONSE
100
90
80
70
60
50
40
30
0-17.9
18-35.9
36-53.9
54+
LATENCY (Seconds)

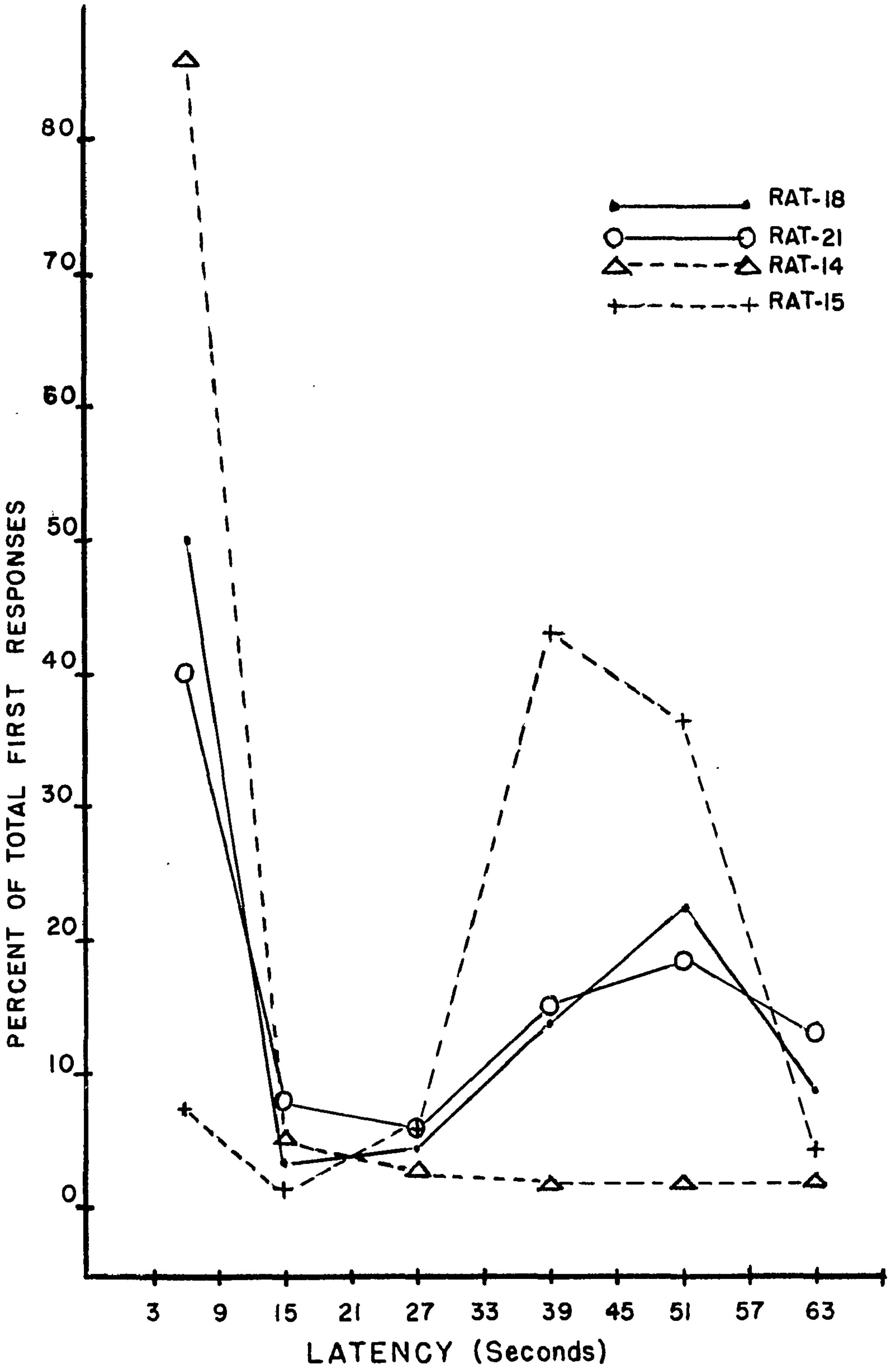
respects, quite similar to those gradients based upon total responding. Unlike the gradients based upon total responding, first response latencies above 36 seconds have supported accuracy levels which are reliably in excess of CRF values. This was essentially the same schedule enhancement of CRF accuracy observed in the basic fixed-ratio schedules (Figure 3).

The frequency data from which these first response accuracy functions were derived are shown in Figure 11. The percentage distribution of the 250 latencies (S+ and S-) which terminated the interval pause demonstrated the tendency for the fixed-interval schedule to divide the distribution of first responses into two distinct latency populations. The first, a population of short latencies peaking in the initial two seconds of the interval, was associated with accuracy levels which closely approached chance values. The second peaked from 6 to 18 seconds prior to the period of reinforcement availability and was associated with very high response accuracy.

Changes in Discrimination Ratio (Rats 18 and 21)

Changes in the overall percentage of S+ responding which were induced by the several values of S-, S+ disparity were shown in Table 10. Frequency data were summed over the complete sample of 250 cycles, and the relative frequency of S+ responding derived from these totals. With the exception of a single reversal in the data for Rat 21,

Figure 11. Percentage of total first responses distributed as a function of latency for the four fixed-interval animals. S-/S+ = 0 for all data.



RAT-18
RAT-21
RAT-14
RAT-15
80
70
60
50
40
30
20
10
0
PERCENT OF TOTAL FIRST RESPONSES
3
9
15
21
27
33
39
45
51
57
63
LATENCY (Seconds)

TABLE 10

Proportion of Total Fixed Interval Responses to the Lever Associated With the S+ as a Function of Discrimination Ratio

S- /S+ (Ft.Candles)	Percent S+ Response	
	Rat 18	Rat 21
0[a]	.90	.85
.04	.85	.79
.15	.75	.82
.28	.69	.66
.61	.56	.52

[a] Indicates Unilluminated S- Display.

(S-/S+ = .15), the data showed a systematic reduction in proportion of S+ responding as the discrimination ratio was increased.

The within-cycle accuracy changes which resulted from reduced S-, S+ disparity (Figure 12) seem to be independent of temporal location within the interval. As the disparity became smaller, there was a systematic and relatively uniform downward displacement of the error gradients. The within-cycle changes continued to be consistent with the tendency toward more accurate discrimination later in the cycle. This displacement was less pronounced in the case of Rat 18, but its regularity for both animals was apparent. It should be noted that the single exception to this parametric displacement of the accuracy gradient occurred at the third value of the discrimination ratio, (S-/S+ = .15) for Rat 21. This discrepancy reflects the higher overall percentage of S+ responding previously noted in Table 10. The data points associated with responses occurring after 54 seconds have been shown as unconnected points to the right. The overall percent of S+ responding during CRF was shown as a single disconnected point (labeled CRF) at the upper left of each panel.

The displacement of the accuracy gradients can be more readily conceptualized by reference to Figure 13. Here the local accuracy which prevailed in each third of the interval has been plotted as a function of the overall percent correct controlled by the various values of the discrimination ratio. The data for Rat 18 were representative of the

Figure 12. Proportion of total responses to the S+ as a function of successive 18-second portions of the fixed interval for all five values of the discrimination ratio. Data for the CRF condition is shown as an unconnected point at the left. AD = 0 for all data.

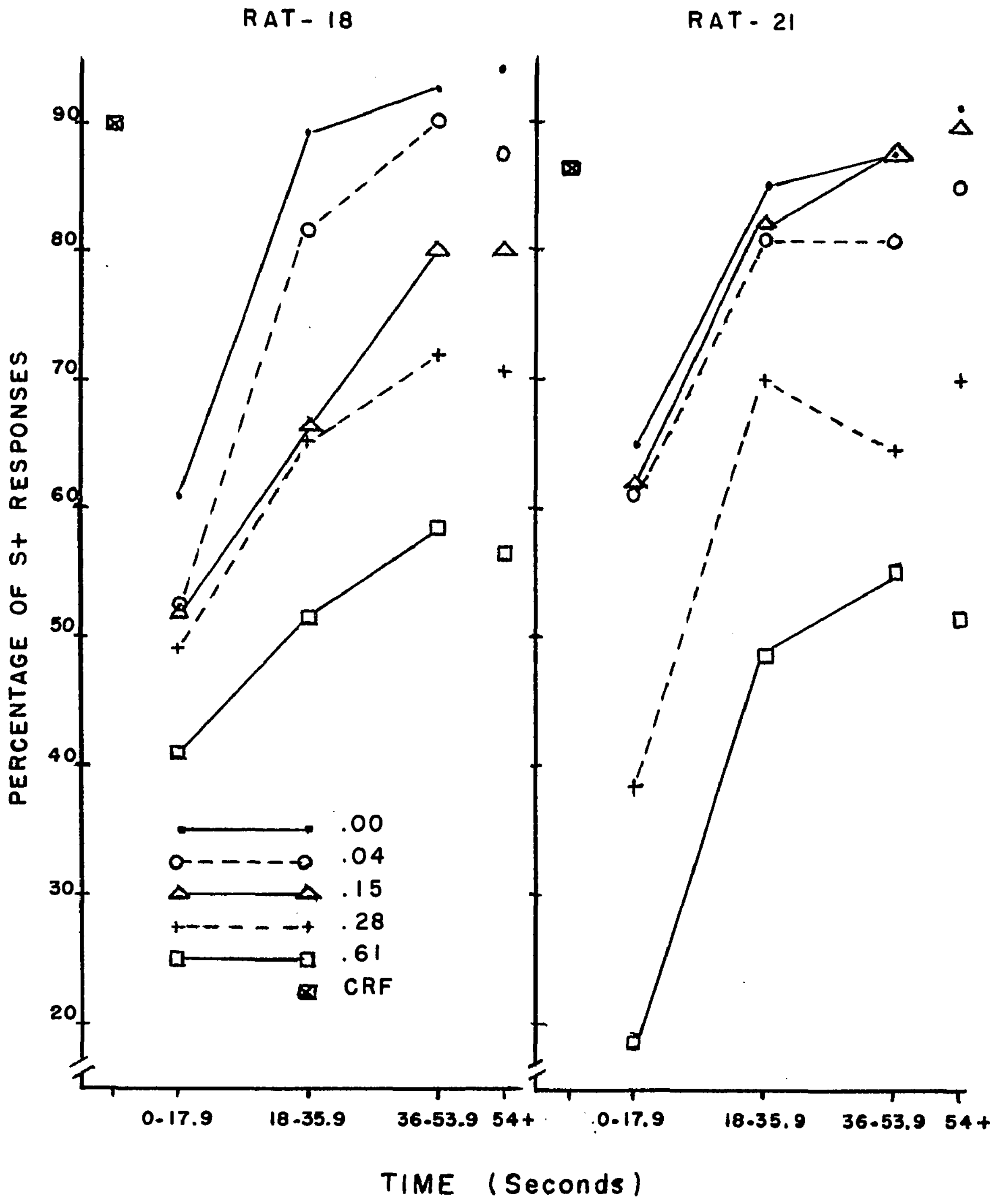
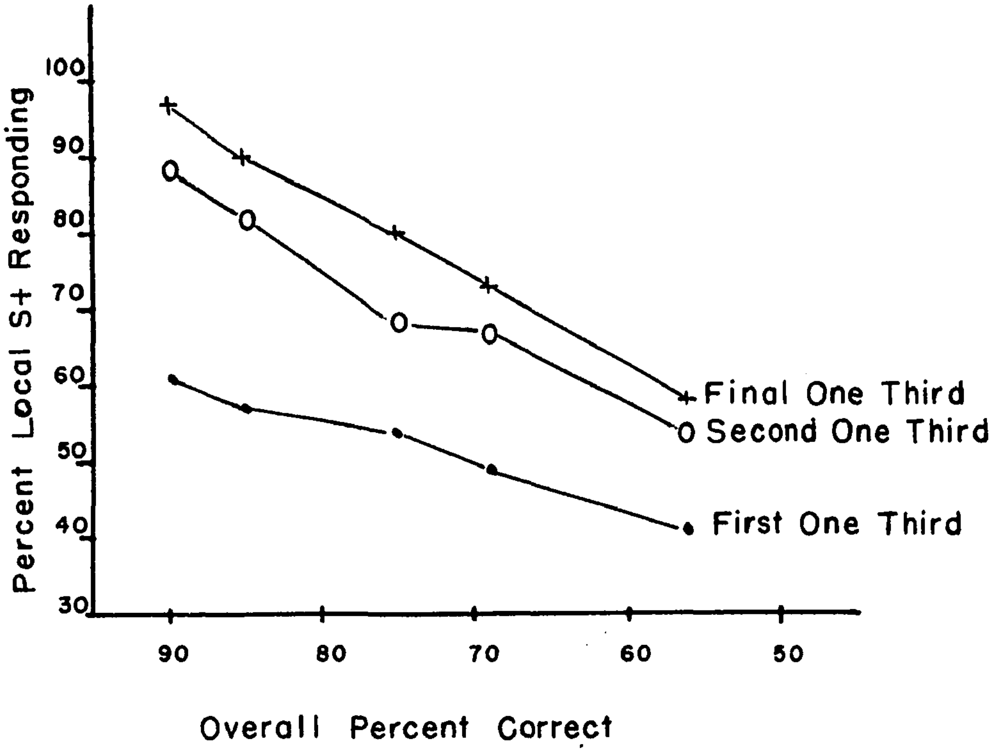

RAT- 18
RAT- 21
PERCENTAGE OF S+ RESPONSES
90
80
70
60
50
40
30
20
0-17.9
18-35.9
36-53.9
54+
TIME (Seconds)
.00
.04
.15
.28
.61
CRF

Figure 13. Proportion of responses to the S+ in each third of the fixed interval is shown as a function of the overall accuracy maintained by the five values of the discrimination ratio. Data are for Rat 18 only.


Percent Local S+ Responding
100
90
80
70
60
50
40
30
90
80
70
60
50
Overall Percent Correct
+ Final One Third
O Second One Third
● First One Third

data for both animals. The approximately linear relationship between local accuracy and overall accuracy was apparent for all three functions. In what might otherwise be considered a random or uncontrolled performance, the regularity of the "first third" data was of particular interest. The relative slopes of the functions indicate that the rate of accuracy change in the first third of the interval was only slightly less than that occurring in the final two thirds of the interval.

Within the limits of the present experiment, the data demonstrate a general independence between the slope of the within-cycle accuracy function, and the overall level of accuracy. Local accuracy within each third of the interval was uniformly reduced, while accuracy differences between temporal thirds of the interval were maintained without regard to S-/S+ value.

Changes in Schedule Variability (Rats 14 and 15)

Response rate data resulting from changes in the variability (average deviation - AD) of the interval schedules has been shown in Figure 14 for Rat 14, and in Figure 15 for Rat 15. The curves show the mean number of responses (S+ and S-) which occurred in successive six-second portions of each interval cycle. Total responding was averaged over a sample of time periods whose number progressively decreased through that portion of the interval in which probability of reinforcement was greater than zero. Responses occurring within any time interval in

Figure 14. Mean number of responses occurring in successive six-second portions of both the fixed and variable interval schedules. Responses which occurred during periods of reinforcement availability have been deleted. The data are for Rat 14 only. S-/S+ = 0 for all data.

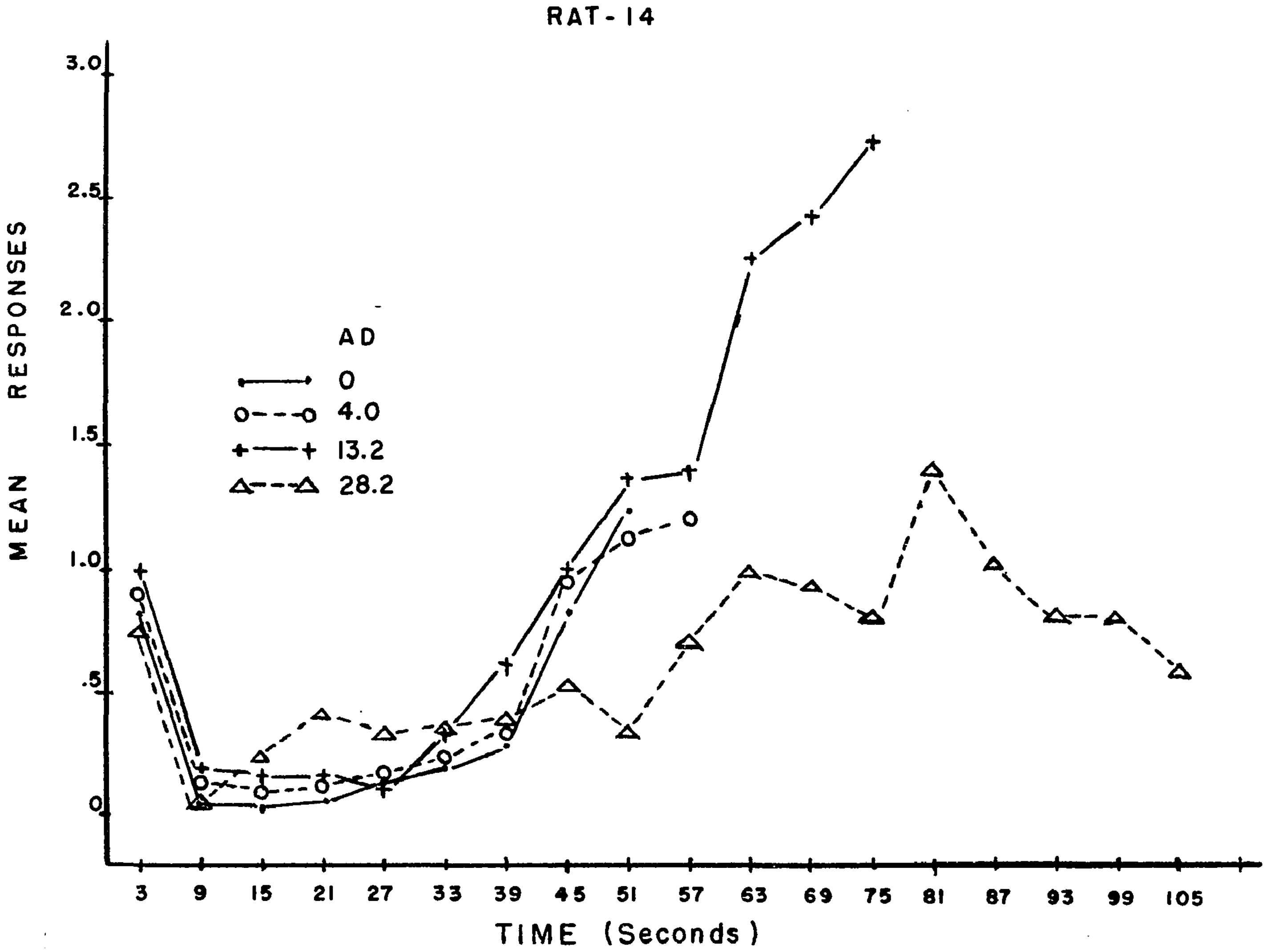
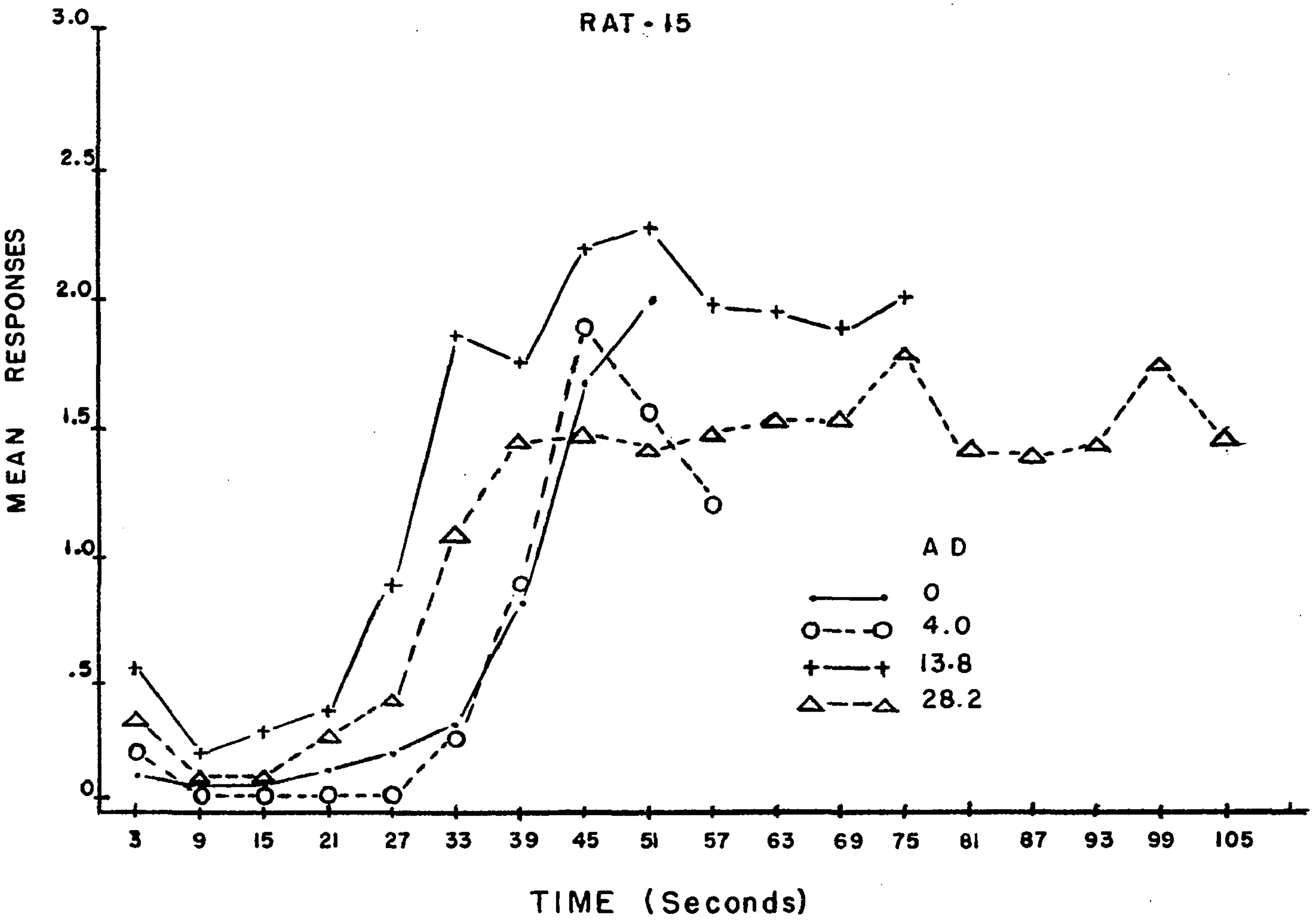

RAT-14
MEAN RESPONSES
3.0
2.5
2.0
1.5
1.0
.5
0
AD
0
4.0
13.2
28.2
3
9
15
21
27
33
39
45
51
57
63
69
75
81
87
93
99
105
TIME (Seconds)

Figure 15. Mean number of responses occurring in successive six-second portions of both the fixed and variable interval schedules. Responses which occurred during periods of reinforcement availability have been deleted. The data are for Rat 15 only. S-/S+ = 0 for all data.


RAT - 15
MEAN RESPONSES
3.0
2.5
2.0
1.5
1.0
.5
0
TIME (Seconds)
3
9
15
21
27
33
39
45
51
57
63
69
75
81
87
93
99
105
A D
0
4.0
13.8
28.2

which reinforcement was available have been dropped from the data shown in these figures. This was done because reinforcement necessarily terminated the interval at the time of the reinforced response. For both animals we see, in the zero variance condition (FI), the occurrence of the same scallop pattern previously noted in Figure 8. At locations below 54 seconds, changes in AD have produced only minor distortions in the previously established scallop.

The schedule of greatest variability for Rat 14 was the only instance in which the scallop pattern did not appear. There was some tendency for the more variant schedules to engender higher mean values. This was particularly apparent in the data for Rat 15. At temporal locations beyond 54 seconds, the data displayed two different response patterns. For Rat 15, mean responses peaked at approximately the 36th second, and then showed a tendency to decline as the interval was timed out. This was consistent with the final schedule for Rat 14, but not with the less variable schedules for the same animal, in which terminal rates were maintained to reinforcement.

The overall percentage of S+ responding maintained by the several levels of schedule variability were shown in ~~Figure~~ Table 11. Data for both animals concurred in demonstrating that accuracy is not controlled by changes in the AD of the schedule.

The within-cycle accuracy functions generated by the various interval schedules were shown in Figure 16. Taken as a whole, the

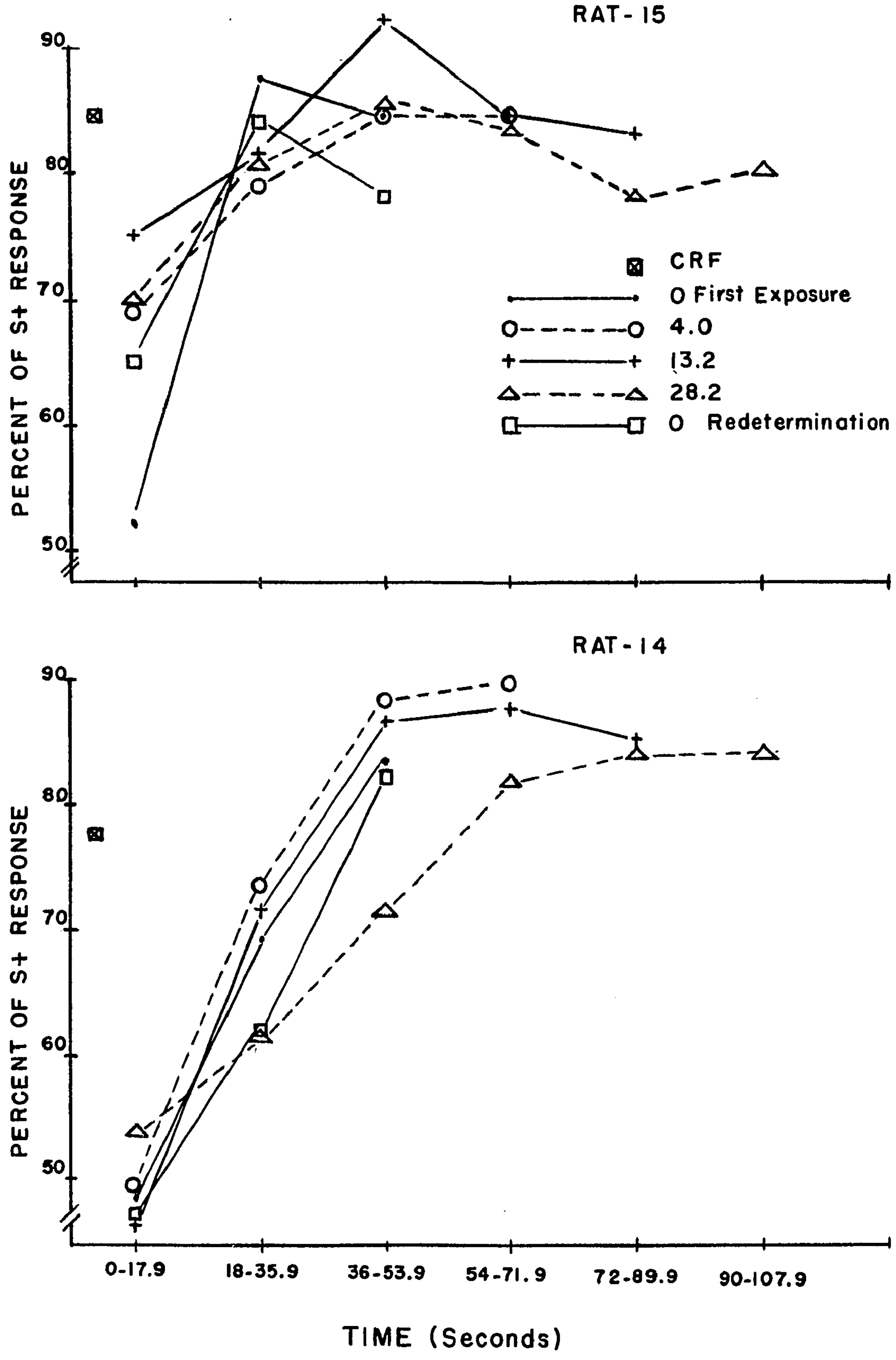
TABLE II

Proportion of Total Responses to the Lever Associated With the S+ as a Function of Schedule Deviation for the Interval Schedules

Average Deviation	Percent S+ Response	
	Rat 14	Rat 15
0[a]	.77	.84
4.0	.78	.83
13.2	.77	.86
28.2	.72	.82

[a] Fixed Interval

Figure 16. Proportion of total responses to the lever associated with the S+ as a function of successive 18-second portions of both the fixed and variable interval schedules. Responses which occurred during periods of reinforcement availability have been deleted. Data are shown separately for Rat 15 (upper panel) and Rat 14 (lower panel). S-/S+ = 0 for all data.


RAT-15
90
80
70
60
50
PERCENT OF S+ RESPONSE
CRF
0 First Exposure
4.0
13.2
28.2
0 Redetermination
RAT-14
90
80
70
60
50
PERCENT OF S+ RESPONSE
0-17.9
18-35.9
36-53.9
54-71.9
72-89.9
90-107.9
TIME (Seconds)

most notable aspect of this data was the apparent insensitivity of the accuracy distributions to changes in the temporal distribution of reinforcement availability. For Rat 15, the advent of the least variable schedule (AD = 4.0) resulted in a slight flattening of the gradient, brought about primarily by an increase in S+ responding in the initial third of the cycle. Further increases in schedule variability did not produce further modification of this general shaped function. In the case of Rat 14, the only change was a slight flattening of the gradient at the most variable schedule (AD = 28.8). The VI schedules of the present study showed many rate-of-response features characteristic of fixed interval. The persistence of the FI scallop probably relates to the well-established FI performance that preceded changes to the VI contingencies. The discrimination data should be evaluated with respect to this persistence of FI-like performance.

Subsequent to the three VI schedules, Rats 14 and 15 were returned to FI-54 seconds under conditions identical to their initial exposure to that contingency. Although this recovery procedure produced response rates which were higher than those observed on the first exposure, the distribution of responses within the cycle and the probability of S+ responding were almost identical under both conditions.

Both FR and FI schedules were found to control a systematic increase in first response accuracy as a function of latency. In contrast with the FR, the interval performance was characterized by within-cycle accuracy gradients which were almost point-for-point replications of the first response data. Both accuracy gradients resulted primarily from a reduction in local accuracy in the early portions of the interval.

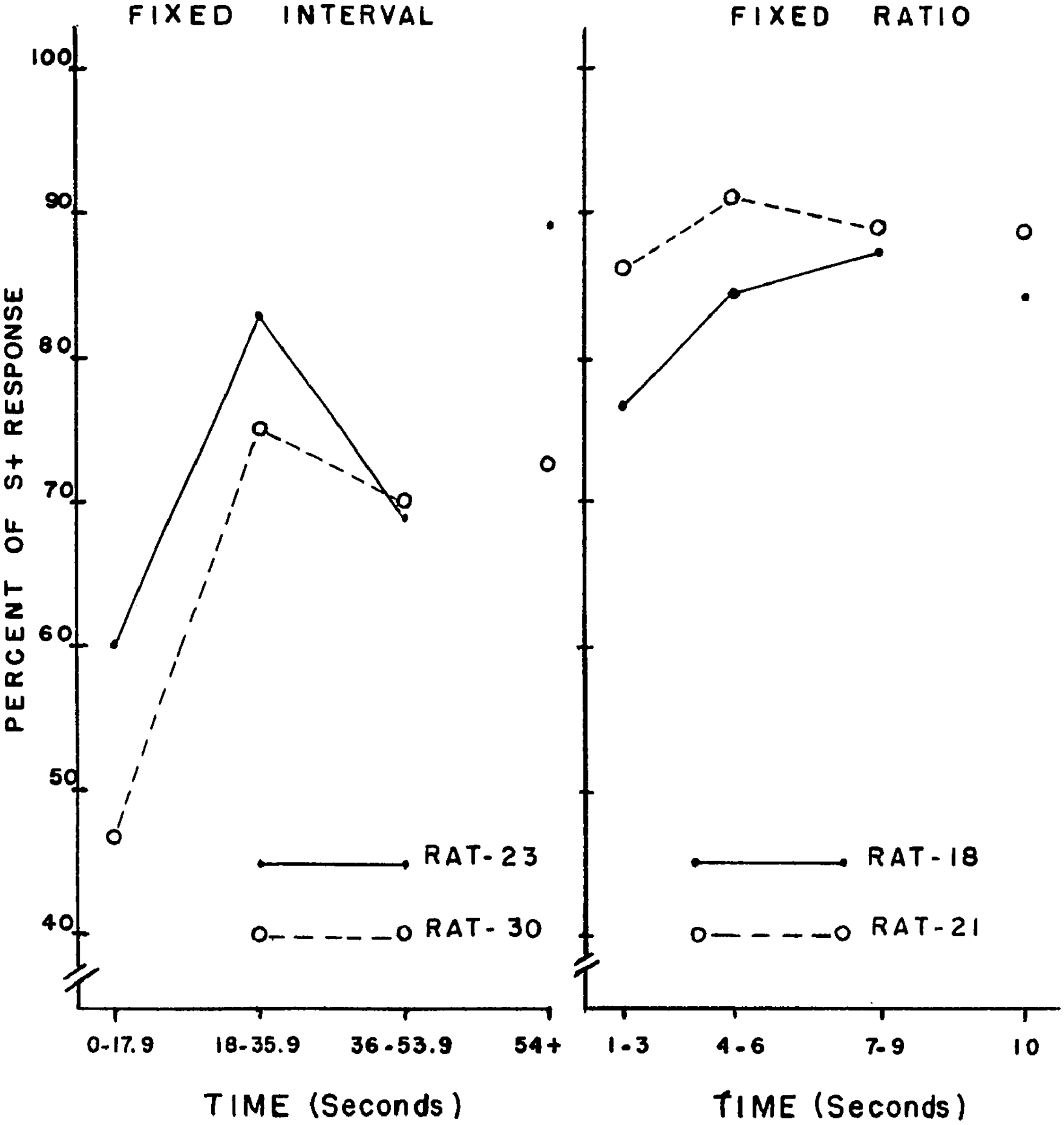
The articulation of the accuracy gradients was not substantially affected by manipulation of the discrimination index. Accuracy was reduced uniformly in each third of the interval. Manipulation of the average deviation of the interval was without substantial effect.

Recovery Data

After the phase of the experiment concerned with brightness discrimination was completed, Rats 18, 21, 23 and 30 were again exposed to CRF (see Table 1). Subsequently, the FR animals (Rats 23 and 30) were placed on a FI and the FI animals (Rats 18 and 21) were placed on FR.

Within-cycle changes in the relative frequency of response to the S+ has been shown in Figure 17 for all four animals. Although the influence of the previous schedule was suggested for both FI (left panel) and FR (right panel) schedules, the patterns distinguishing ratio and interval schedules were apparent. A slight gradient remained in the FR data, while in the FI data the relative frequency of an S+ response in the first 18 seconds was strongly depressed from the levels shown by these subjects when reinforced on FR. The reversal between the second and third 18-second periods differed from the performance of animals initially trained on FI.

Figure 17. Proportion of responses to the S+ for fixed interval following extended fixed-ratio training (left panel) and fixed ratio following extended fixed-interval training (right panel) shown as a function of successive thirds of the schedule. S-/S+ = 0 and AD = 0 for all data.


FIXED INTERVAL
FIXED RATIO
PERCENT OF S+ RESPONSE
100
90
80
70
60
50
40
RAT-23
RAT-30
RAT-18
RAT-21
0-17.9
18-35.9
36-53.9
54+
1-3
4-6
7-9
10
TIME (Seconds)
TIME (Seconds)

Discussion

Baseline Performance

The basic fixed-ratio and fixed-interval schedules used in this research are operationalized in a manner which is sufficiently different from standard free operant procedures to warrant comparison of simple rate data obtained under the present procedures with data reported when more conventional schedule specification is utilized.

In the fixed-ratio case, the presence of an extended period of non-response terminating in an abrupt transition to a high constant rate appears to be in overall conformity to the typical fixed-ratio behavior. The overall response pattern does not appear to fall outside the range of variation to be expected of data from more conventional fixed-ratio procedures (Ferster & Skinner, 1957). The average 1.0-second response latencies (from stimulus onset to response) maintained by the present FR schedules may be compared with the 0.4- to 0.8-second interresponse times which Blough (1963) has found to be characteristic of free operant FR performance when pigeons are used as subjects. Considering the somewhat lower free operant rates to be expected from rats, the 0.2- to 0.4-second differences between Blough's free operant pigeon data and the present rat data seem fairly small. It is possible that these small differences are - in part - a product of the intertrial interval, but there is certainly no reason to suspect that the overall cohesiveness of the response sequence has been significantly disrupted by the discrete-trials procedure.

In the case of the FI animals, the systematic acceleration of responding observed in the present experiment is characteristic of the "scallop" pattern which most investigators, (Fry, Kelleher & Cook, 1960; Gollub, 1964; Dews, 1962), report as characteristic of well-established fixed-interval performance.

Insofar as similar rate patterns evidence similar stimulus control, the scheduling operations used in the present experiment exert control over response frequency which is equivalent to more traditional free operant procedures.

Fixed Ratio

The present study has shown nearly perfect accuracy for responses which terminate extended post-reinforcement pauses. This gradient of greater accuracy with longer pausing seems to imply joint control of the response by the exteroceptive discrimination and stimuli related to the temporal aspects of the schedule.

The general effect is reminiscent of a study reported by Miller and Ackley (1970) in which a light and tone were alternately correlated with responding maintained by a FI schedule. Comparison of response rates in the presence of the individual stimuli and their compound revealed that the compound stimulus-controlled rates which could be described in terms of simple summation of the component rates. This was observed for all temporal locations within the interval. These data replicate the results obtained by Wolf (1963), who employed a similar experimental paradigm but tested for stimulus control by both S^D's and their compound during extinction. The strength of stimulus control which accompanies temporal extension of the pause is suggested by the observation that accuracy at pause durations in excess of 36 seconds is approximately the same for the several levels of discrimination difficulty. Shorter pauses, however, showed an accuracy hierarchy related to the brightness disparity. The occurrence of this latency-accuracy relationship under conditions which seem to preclude response mediation suggests a strong temporal control over the onset of responding, with the probability of response and the degree of accuracy increasing concurrently.

It might be reasonable to expect evidence of enhanced stimulus control to be correlated with proximity to reinforcement (or other logically related measures of within-schedule location). It is not unusual to find that in discrete-trials procedures, interresponse times are shorter in the final portions of the ratio run, or that remoteness from reinforcement has a deleterious effect upon accuracy of responding (Mintz, Mourer & Weinberg, 1966; Nevin, Cumming & Berryman, 1963). In the present case, however, the gradient of first response accuracy represents the only instance in which measures of stimulus control are positively correlated with proximity to reinforcement.

In contrast to responses which terminate the pause, responses during the run are not differently controlled by proximity to reinforcement, thus suggesting a response sequence maintained independently of the regularities of reinforcement delivery. Changes in the average deviation of the ratio were without substantial effect, and the progressive reduction in accuracy as the ratio is counted out could in no way suggest control by the discriminative aspects of reinforcement delivery. In fact, this observation seems to imply partial loss of schedule control as reinforcement is approached. In all experimental conditions, the data suggest a homogeneous and highly interdependent sequence of responses maintained independently of local changes in reinforcement probability.

These data can be understood within the context of Dews' (1962, 1969) ideas concerning the action of reinforcement. Working with the FI schedule, Dews (1965, 1966) has shown that the typical response pattern is not disrupted by the insertion of several S^{Δ}s periods into each cycle. Dews interprets his data as showing that local rates of response are not controlled by a continuous chain of mediation behavior. Instead, Dews argues that the pattern of within-cycle responding is not dependent upon response conditions prevailing at the moment of reinforcement effect. The strengthening of responses remote from reinforcement is presumed to be dependent upon temporal proximity to reinforcement and independent of both intervening responding and the similarity between the remote behavior and the behavior at the time of reinforcement delivery.

This point of view finds support in the observation (Dews, 1960) that delays of reinforcement up to 100 seconds are effective in maintaining substantial rates of response. A more direct confirmation has been provided by Catania (1971) who has been able to show that each response preceding the one which produces a reinforcement appears to make an independent contribution to subsequent rate. In conformity with Dews' prediction, Catania finds that the contribution of each response to subsequent rate is determined by the delay of reinforcement for that response.

Although Dews (1962) has pointed out the formal similarity between this notion and Hulls' (1932) goal-gradient hypothesis, he does not favor its use in this context. It is Dews' opinion that the identification of mediating mechanisms should be a result of experimental demonstration rather than theoretical speculation.

In the specific case of fixed ratio, Dews argues that "... The possibility should be considered that the high rates of responding engendered by fixed-ratio schedules may come about as follows: The higher the average rate of responding on an FR schedule, the closer, temporally, the initial response and all subsequent responses in the FR are to reinforcement, and therefore the greater the retroactive enhancing effect of that reinforcement. This will tend to increase the rate of responding, which will in turn tend to bring the responses closer to reinforcement which will increase rate further. Thus there is in effect a positive feedback situation in which random increases in rate will tend to be self-enhancing." (Dews, 1962, p. 373)

A process of "response compacting" of the type envisioned by Dews has been documented by Blough (1963). This investigator has recorded changes in IRT distribution when a VI-4 baseline is shifted to a FR-30. The IRT distribution for VI showed a high variability with a slight peak at 0.40 seconds, and the balance of all IRT's evenly distributed between 0.70 and 6.0 seconds. The first 100 minutes of FR training produced IRT distributions characterized by short durations and very low variance. IRT's below 0.50 seconds account for a large percentage of total response. In well-trained FR-25 performance, Blough's data indicate that almost 100 percent of all within-run IRT's fall between 0.20 and 0.40 seconds.

If the notion of the "schedule control" of a performance can be understood to imply control of response emission by antecedent stimulus events arising from, or highly correlated with, the discriminative aspects of reinforcement delivery, then one logical consequence of a progressive reduction in IRT must be a reduced likelihood of effective schedule control. As the response sequence becomes behaviorally more stereotyped and temporally more compacted, there must be fewer schedule correlated stimuli intervening between responses and therefore a reduced likelihood of differential within-cycle behavior. Control of individual response onset might then shift to stimuli arising from the antecedent response. In a sense, the question here concerns the relative contributions toward the control of responding by preceding responses *per se* as opposed to any other sources of control.

There is, in fact, independent evidence to show that short IRT's of the type which predominate in FR schedules are extremely resistant to control by differential reinforcement (Staddon, 1965; Reynolds 1966). More to the point, Blough (1966) manipulated the relative frequencies of different interresponse times by reinforcing only those that, over a preceding interval of time, occurred least frequently. He found that IRT's shorter than 0.8 seconds, in contrast to longer IRT's, were not well controlled by reinforcement.

If Blough's 0.8-second free operant IRT's seem reasonably similar to the (average) 1.0-second latencies in the present experiment, then the absence of within-run variation becomes understandable in terms of a response sequence which is not differentially controlled by reinforcement delivery.

This general analysis therefore assumes that in the well-established FR performance, the termination of a temporally controlled post-reinforcement pause initiates a behavioral sequence in which response occurrence is controlled by the preceding response, (and/or unrecorded prior behavior occurring during the time out), and the momentary S+, S- position. The strongest form of this argument would assert that the unique contribution of the <u>schedule</u> of reinforcement availability would be related to: a) the initiation of the response sequence, and b) the delivery of reinforcement which acts to terminate responding.

Even if this set of assumptions is reasonably consistent with the present data, previous research examining within-cycle accuracy (Mintz, Mourer & Weinberg, 1966; Nevin, Cumming & Berryman, 1963; Zeiler, 1968) is in unanimous disagreement. In each case these authors describe within-cycle accuracy patterns which resemble the FI accuracy gradients of the present experiment.

Although these contradictory results are not easily reconciled, a subsequent replication of the basic ratio procedure seems to implicate procedural differences. The general problem is that of the discrimination of different locations within a response sequence. Keller and Schoenfeld (1950 p.205) point to the difficulty of discriminating a homogeneous sequence[6] and in fact suggest that if it exists at all, pure homogeneity is

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[6] There is no implication of a chain of behavior in which the preceding reponse acts as an S^D for (or otherwise controls) the subsequent response. The momentary focus of interest is upon homogeneous versus heterogeneous response sequences, without concern for exact mechanisms of control.

rare. One possibility is to follow Keller and Schoenfeld's suggestion and assume that the more heterogeneous the sequence, the greater the likelihood of a discriminated performance. One way in which a moderately homogeneous sequence of lever press responses may be modified is to introduce procedures which have the effect of extending interresponse times. The amount of unmeasured behavior intervening between lever presses should increase in direct proportion to the time between responses. In this way a more heterogeneous stream of behavior would be produced. Thus procedures which tend to produce more extended interresponse times might permit the parallel development of differential responding within the run. In fact, the co-occurrence of longer - more easily schedule controlled - IRT's and within-cycle accuracy gradients has persuaded Bigelow (1971) that differential within-cycle accuracy occurs only with "time consuming" operants as opposed to more "instantaneous" response classes.

Bigelow's time consuming operant is a 4.5-second DRL (Differential Reinforcement of Low Rate) requirement. These DRL response units were then maintained on an FR-20 schedule of food reinforcement. Bigelow reports that the proportion of responses satisfying the DRL requirement was sharply depressed in the first quarter of the ratio and increased systematically as the ratio was counted out. In the first quarter of the ratio, correct responses occurred at the rate of 2.5 per minute, compared to a rate of about 8 per minute in the final quarter of the ratio.

The nineteen 4.5-second IRT's mandate a minimum duration of 85.5 seconds, but examination of cumulative records for total responding indicates an actual run time in excess of 200 seconds.

DeLorge (1969) has observed the same general response pattern when a DRL-10 is reinforced on an FR-5 schedule. This author is of the opinion that the fixed number of ten-second DRL components imparts strong fixed-interval properties to the schedule. In common with Bigelow (1971), DeLorge suggests that a one-second DRL component might well produce "responding more similar to typical FR-5 behavior."

Stubbs (1968) has also reported FR accuracy gradients using a procedure which is closely related to that of Bigelow. Stubbs' research was concerned primarily with an examination of the discrimination of stimulus duration in the pigeon. This investigator used a three-key paradigm in which the center key remained on (white) for a predetermined period of time and then went off automatically. The two side keys were illuminated, one red and the other green. If the center key light was of short duration (1, 2, 3, 4, or 5 seconds), then a response to the red key was correct. If the center key was of long duration (6, 7, 8, 9, or 10 seconds), then the green key was correct. This procedure was reinforced with food on a FR-6 schedule. Correct responses which the schedule did not reinforce with food were followed by a 0.5-second illumination of the magazine light. Error responses were followed by a

30-second time out. Response accuracy was found to be lower at the beginning of the FR than at the end.

Here again the temporal duration of the run seems important. The average duration of the center key stimulus was, of course, 5 seconds, yielding a minimum run (6 responses) of 30 seconds. If allowance is made for an average of one error response per ratio cycle, then we have a sequence of 7 responses distributed over a 60-second interval.

Except for the fact that their component operants do not require multiple responding, these procedures are closely analogous to extended tandem (Ferster & Skinner, 1957) or second order (Kelleher, 1966) schedules. It is common for such procedures to produce a marked gradient of within-cycle[7] control. Gollub (1958) reports data for a FR-5 (FI-1)[8] schedule in which pauses in the first two components averaged 6.5 minutes, while the final three components were completed in about 1 minute each. These observations have been confirmed by Kelleher and Fry (1962).

It is possible to interpret this data as implicating the "time consuming" operant only insofar as the response class, or other procedures, act to produce an extended run duration. This possibility is suggested

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[7] Primary S^R to primary S^R.

[8] In Ferster and Skinner's notation a tandem FI-1, FI-1, FI-1, FI-1, FI-1 schedule.

by research reported by Zeiler (1968). Using four pigeons as subjects, this investigation maintained a three-hue simultaneous discrimination with FR reinforcement. Fixed-ratio values ranged from 2 to 190. The schedule was a somewhat unorthodox one in that any response, irrespective of hue, served to advance the ratio, but once the sequence of unreinforced responses had been completed, reinforcement was contingent upon response to the S+. There were no trials, the stimuli being continuously available regardless of the character of previous responding.

At FR values below 20, the reinforcement contingency was successful in maintaining 100% correct (S+) responding in all four animals. (For one of the pigeons, 100% accuracy was maintained throughout the experiment.) The remaining three birds exhibited a progressive increase in S- responding as the ratio was raised from approximately FR-20 to FR-190. For these animals, the distribution of within-cycle errors followed the same general pattern found in the FI data of the present experiment. The percentage of correct responses was at chance levels in the first quarter of the ratio, increased systematically over the second and third quarters and became asymptotic at approximately 98% correct in the final quarter. At ratio values above 20, the reinforcement contingency loses control of responding early in the ratio. Above FR-30, increases in ratio requirement are satisfied almost exclusively by S- responding occurring in the first half of the ratio.

It is evident that any interpretation of these data must be tempered by the fact that run duration and number of responses are confounded. Although it is possible that the appearance of the accuracy gradients results from increases in the response requirement, the argument for temporal control seems equally attractive.

In each case, an FR accuracy gradient appears in conjunction with procedures which dictate extended run times. The data does not permit a more detailed analysis, but the overall picture is compatible with the suggestion that differential within-cycle accuracy can be related to a process in which response occurrence, remote from reinforcement, is brought under partial temporal control.

Mintz, Mourer and Weinberg (1966) report data in which accuracy gradients appear in conjunction with run durations which appear somewhat at variance with this analysis. These investigators report data for zero delay matching-to-sample maintained on an FR-9 schedule, which included an added stimulus counter consisting of an array of ten (10) small lamps. The first correct response illuminated the first light in the display, and an additional lamp was illuminated following each correct response, with reinforcement occurring in the presence of all 10 illuminated lamps. The time out between trials was 0.6 seconds.

Accuracy gradients which ranged from an initial 79% to terminal values of 97% were found in a schedule which typically contained fewer than 20 responses and approximately 9 seconds or less in time outs. Latency data was not available, but extensive informal observation indicated extended post-reinforcement pausing in conjunction with response latencies substantially below 1.0 second. These observations are consistent with latency data reported by Mintz, Mourer and Stein (1968) for a similar experimental procedure. The 29-second run duration generated by this procedure is somewhat shorter than that observed in studies previously cited.

The Mintz, Mourer and Weinberg (1966) procedure can be interpreted as an extended chain schedule in which each correct match occurs in the presence of a different exteroceptive stimulus. Several investigators (Gollub, 1958; Findley, 1962; Ferster and Skinner, 1957) have shown the early components in an extended chain are less well controlled by the schedule of primary reinforcement than components later in the chain. This phenomenon is not, however, observed in tandem schedules (Gollub, 1958). Kelleher (1966) has suggested that this effect could be related to the decreased effectiveness of conditioned reinforcers which are remote from primary reinforcement, but whatever the exact mechanisms of control, it is clear that the correlated stimulus could tend to enhance any pre-existing level of differential within-cycle responding.

At this point, it would be helpful to examine data reported by Nevin, Cumming and Berryman (1963). Simultaneous three-hue matching-to-sample was maintained on fixed ratios of 3, 6, and 10 responses and on a VR-3. Each trial required a series of five responses on the center key (FR-5), and completion of this sequence illuminated the side keys. The intertrial interval was one second. There were no differential consequences of an error response.

Highly articulated accuracy gradients were observed at all FR values for all three subjects. Accuracy, which approached chance levels immediately following reinforcement, became asymptotic at approximately 95% in the final portion of the ratio. In addition, the latency from center key onset to the completion of the fifth center key response was found to decrease systematically with increasing trials after reinforcement - in essence, a fixed-intervaltype scallop for center key responding.

Each FR schedule contained "n" response units, consisting of an FR-5 (center key) and one (1) side key response. Consideration of the latency data indicates an average (conservatively) of three seconds per response unit[9], thus mandating minimum run durations of 12, 24, and 40 seconds[10] for the FR-3, -6, and -10 schedules, respectively. Although the three-second response unit might be considered a "time

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[9] This writer's estimate based on data presented by Nevin et al. (1963).

[10] This analysis assumes no error responding. Inclusion of the small population (about 5%) of response units terminated by incorrect matches would inflate these figures slightly.

consuming" operant, comparable to Bigelow's (1971) 4.5-second DRL requirement, the 40-second minimum run duration generated by the FR-10 is generally compatible with data previously cited, as is FR-6 data. The very short run duration for the FR-3 data does not, however, seem compatible with the assumption that temporal remoteness from reinforcement controls reduced accuracy.

Nevin, Cumming and Berryman do not suggest a reason for the emergence of the within-cycle accuracy gradients, but they do observe that "all subjects ... developed post-reinforcement pauses during the first few days of exposure to each FR schedule. This development proceeded concurrently with the reduction in accuracy on trials immediately following reinforcement" (Nevin, et al., 1963, p. 153). The FR-3 data therefore raise the possibility that depressed accuracy may be related to those factors which produce pausing rather than to temporal remoteness from reinforcement <u>per se.</u>

This relationship between the development of post-reinforcement pausing and reduced accuracy must also have occurred in the Zeiler (1968) data. At FR values below 20, pigeons produce little or no FR pausing and it is at these ratio values that 100% correct responding was maintained. Zeiler does not make direct comparisons but examination of his data does seem to indicate a positive correlation between pause duration and frequency of error responding. Error responses occur almost exclusively in the early portions of the ratio.

The reports of Bigelow (1971) and Stubbs (1968) do not lend themselves to this type of analysis. In each case, however, schedules which would be expected to produce substantial pausing control depressed accuracy in the early portions of the run. This data seems clear enough to warrant the inference of some relationship between the emergence of stable pausing (or extended IRT's) and a within-cycle accuracy gradient.

In each of the experiments previously cited, we have been able to demonstrate a possible relationship between reduced response accuracy in the early portions of the run and two temporal aspects of the fixed-ratio cycle. The possibility that a temporally extended run duration might allow for the emergence of some level of subsidiary temporal control seems evident. Additionally, this general idea is particularly compatible with Dews' (1962) assumptions concerning ratio control. It will be recalled that Dews postulates a delay of reinforcement effect which is essentially temporal in nature. Responses proximal to reinforcement are being more strongly controlled, while responses distant from reinforcement are less strongly under the influence of reinforcement. This notion would predict that if a time consuming operant or extended time out prevented the response sequence from becoming compacted, a temporally defined gradient of differential control would exist within the ratio run. Increased FR requirements would tend to produce the same effect. Portions of the run temporally remote from reinforcement would be less strongly controlled. Under these conditions, the reduced schedule control early in the cycle might be expected to engender the extended interresponse times (or pauses) which appear to be correlated with the emergence of reduced accuracy. In this way the same general principle which Dews uses to account for the development of high rate in free operant ratio performance can also be applied to an understanding of FR accuracy gradients.

The present analysis has attempted to implicate the temporal aspects of the schedule in the development of within-cycle accuracy gradients. Some of the important temporal aspects of the several ratio procedures previously cited are compared with those obtained in the present experiment in Table 12. It is apparent that, with the exception of Nevin's FR-3 data, the average run duration obtained in the present experiment is substantially below that typically observed in conjunction with the development of within-cycle accuracy gradients. With the exception of the seven-response sequence reported by Stubbs, actual number of responses is also below that reported in other studies. These comparisons may imply that the absence of accuracy gradients in the present experiment results from a run duration and/or response requirement too short to generate differential temporal control within the run.

Fixed Interval

The within-cycle accuracy functions obtained in the present experiment may be compared with data reported by Clark and Scherman

TABLE 12

Summary of Fixed Ratio Procedures Reporting Within-Cycle Accuracy Gradients

	NOMINAL FR VALUE	NUMBER RESPONSE	PROCEDURE IMPOSED MINIMUM[b] IRT (SEC)	RUN TIME (Sec)	ACCURACY GRADIENT SHOWN
Mourer[a]	FR-10	11	0.350	9.0	NO
Mintz et.al (1966)	FR-10	20	0.600	29.0	YES
Nevin et.al (1963)	FR-10	60	1.0	40.0	YES
	FR-6	36	1.0	24.0	YES
	FR-3	18	1.0	12.0	YES
Stubbs (1968)	FR-6	7	5.0	60.0	YES
Bigelow (1971)	FR-15	19	4.5	150.0	YES
Zeiler (1968)	50-150[c]	50-150[c]	None	Unknown	YES

[a] This experiment.

[b] Real time.

[c] FR values at which substantial error responding was observed.

(1970), who reinforced a two-key matching-to-sample performance on a FI-8 minute schedule of food reinforcement. The data were not consistent in all conditions, but, generally, the percentage of correct matches was depressed following reinforcement and then showed a monotonic increase over progressive quarters of the interval. In most cases the range did not exceed 15%. This was less than half the within-cycle accuracy change observed in the present data.

Fixed-interval accuracy gradients have also been reported by Boren and Gollub (1972),who employed a three-key matching-to-sample problem. Their data for consecutive twelfths of a 48-second interval show 90% accuracy levels in the first four seconds of the interval. Accuracy drops to chance levels at approximately 12 seconds, at which point accuracy increases systematically to 90% levels in the final portions of the interval. The same general accuracy pattern has been observed by Ferster (1960),who reports that performance under a matching-to-sample procedure was least accurate during the second quarter of the FI-10 minute component of a multiple FI-FR schedule. Although these bi-modal distributions do not exactly replicate the monotonic accuracy relations found in the present experiment, the available literature seems to be in reasonably close agreement. When discriminations are reinforced on a FI schedule, accuracy of responding is depressed in the early portions of the interval and then increases to peak values as the interval is timed out.

In the present experiment, the observation that the distributions of first response accuracy are nearly perfect replications of the accuracy gradients based upon total responding suggests an analysis of the fixed-interval response sequence in terms of control by a temporal process. It is, of course, assumed that the data for the population of first responses is devoid of any possible sequential effects related to immediately antecedent responding. The data give the impression that the accuracy of a particular response is controlled by its temporal location within the interval. This implies a gradient of differential control based on temporally correlated stimuli which exert their influence independently of local responding. The within-cycle data do not indicate even partial independence of rate and accuracy measures. In general, the probability that a response will be made shows the same systematic within-cycle changes as the relative frequency of correct responses. It might therefore be reasonable to assume that both are controlled in the same general manner. This would extend the above analysis to accommodate temporal control of response initiation (rate) as well as of accuracy. This analysis is therefore compatible with Dews' (1962) suggestion that delay of reinforcement is the critical variable controlling the fixed-interval response pattern.

This viewpoint also finds support in data reported by Wall (1965). This investigator maintained rats on a fixed-interval 60-second schedule by reinforcing responding on a lever that was introduced every 60 seconds. The fixed interval consisted of a time out (lever withdrawn) which was interrupted once by a second presentation of the lever at some point during the interval. It is Wall's contention that responses to this intermittently presented lever - which were never reinforced - provide an indication of FI discrimination uncontaminated by the effects of free responding. Observed differences in response latency on non-reinforced trials, occurring at different temporal locations, were analogous to differential responding occurring in a free operant procedure. It is Wall's belief that response factors are not essential for the temporal discrimination which underlies the schedule.

Research recently reported by Neuringer (1969) also support this general analysis. This author compared pigeons' preference for delayed reinforcement with fixed-interval schedules of comparable duration. Neuringer reasoned that if delayed and interval reinforcement have the same effect upon responding, subjects should choose the two alternatives with equal frequency. The subjects' indifference to the two reinforcement conditions leads Neuringer to conclude that the time between response and reinforcement controls response probability, whether other responses intervene or not.

This assumption is made more plausible by Ferster and Skinner's (1957) demonstration that the fixed-interval response sequence could be brought under control of an exteroceptive time correlated stimulus. When a fixed-interval performance was developed in the presence of a correlated stimulus clock, these investigators were able to show that reversal of the correlated stimulus resulted in a complete reversal of the local rate pattern in which the pause occurred in the final portion of the interval. However, the reinforcement contingencies quickly altered this clock-imposed response pattern. Ferster and Skinner conclude that "the rate of responding is completely determined by the value of the clock stimulus. Any stimuli from behavior or other stimuli also varying in time, seem to exercise no control." (p. 277)

The general thrust of this data is to build a case against explanations of FI control which are based upon chaining or prior responding. Taken as a whole, the data does not pinpoint specific mechanisms of schedule control, but it would not be inconsistent to suggest control by stimuli directly related to the temporal properties of the schedule.

Further evidence for temporal control can be found in the frequency distribution of response latencies terminating the fixed-interval pause. These distributions are strongly suggestive of the bi-modal distribution of response latencies generated by DRL schedules (Schuster & Zimmerman, 1961; Bigelow, 1971). In both procedures, the first mode follows reinforcement at very short latency, thus suggesting a population of responses controlled by previous responding and/or reinforcement delivery. This interpretation is consistent with observations that the initial mode does not appear when DRL is programmed on a discrete-trials procedure requiring an extended intertrial interval (Logan, 1961; Zimmerman, 1961).

In typical DRL performance, the temporal location of the second mode is critically dependent upon the duration of the interval to be discriminated. At DRL values of 2 seconds (Nevin & Berryman, 1963); 4.5 seconds (Bigelow, 1971); and 10 seconds (Farmer & Schoenfeld, 1964), the second mode reflects a consistent overestimation of the interval. With the observed variability of the IRT, the overestimation represented by the mode corresponds to a substantial proportion of IRT's meeting the DRL requirement. When DRL values are extended to above 20 seconds, most investigators (Malott & Cumming, 1964; Kelleher, Fry & Cook, 1959; Farmer & Schoenfeld, 1964) report a tendency for the second mode to reflect an underestimation of the interval.

These data have been reviewed by Catania (1970), and the reported tendency to underestimate longer intervals was found to be consistent with temporal discrimination data generated by both Sidman Avoidance procedures and temporal judgments of human subjects using the methods of estimation and comparison.

Catania also presents original data which indicates that when pigeons are exposed to a DRLL[11] contingency in which the interval to

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[11] A discrete-trials analogue of the conventional DRL schedule.

be discriminated exceeds 36 seconds, the interval is so seriously underestimated that fewer than 5%[12] of all responses are reinforced. In this case the relationship between the response distribution and the interval to be discriminated is strongly reminiscent of the temporal relation between the second mode of the first response distribution and the 54-second fixed interval in the present data. It is therefore not unreasonable to consider the distribution of first response latencies as reflecting the outcome of a temporal discrimination of the interval.

With few exceptions, both interval and ratio schedules produce a period of non-response immediately following reinforcement. Writers concerned with an analysis of this phenomenon (Ferster & Skinner, 1957; Keller & Schoenfeld, 1950) have tended to view pausing - or at least the initiation of the pause - as a product of the systematic extinction of responding which closely follows reinforcement. Once this process has stabilized, the pause can be viewed as a point of local loss of schedule control. This point of view provides the basis for an analysis of the FI-response pattern in terms of a temporal discrimination.

The temporal discrimination notion is the traditional explanation of FI performance first proposed by Skinner (1938, p. 125). Keller and Schoenfeld (1950, p. 86) state the general notion clearly:

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[12] This writer's estimate based on data presented by Catania, 1970, p. 21, Fig. 1-6.

> "This (the FI scallop) shows that a *temporal discrimination*[13] has been formed. The responses just after eating a pellet are weakened because they are never reinforced, whereas later responses are strengthened because the reinforcement is given later."

The same general notion is supported by Ferster and Skinner (1957) and has been reiterated in current textbooks. Millenson (1967, p. 143), for example, contends that:

> "This cessation of responding (following reinforcement) is a natural consequence of the fact that in the past, responding just after reinforcement was never reinforced. It is a form of *discriminated*[13] extinction..."

This general analysis is consistent with both the bulk of experimental data and the formal properties of the reinforcement schedule. The FI schedule, with unlimited hold, can be described in terms of a sequential discrimination in which an S^D period alternates with an S period, which is terminated with the first reinforced response. Although the experimenter arranges no explicit discriminative stimuli, the differential behavior which the subject correlates with the extremes of the temporal interval, testifies to the presence of effective controlling stimuli not under direct experimental control. It is therefore not at all unreasonable to suggest a response sequence controlled by extinction related (S) stimuli which gradually shift into or are replaced by S^D stimuli.

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[13] Emphasis added.

The accuracy data from the present experiment bring this general analysis into question. The reduced percent of S+ responding which follows reinforcement is not suggestive of a loss of schedule control produced by extinction. When discriminations are subjected to experimental extinction, rate of responding is reduced toward operant level, but accuracy is substantially unaffected.

Cumming, Berryman, Cohen and Lanson (1967) extinguished three-hue matching-to-sample behavior in three pigeons and found that a systematic reduction in rate responding was not accompanied by reduced matching accuracy. Cohen (1969) reports comparable results when a two-key matching problem is extinguished. Similar results were obtained by Nevin (1967),who maintained a simultaneous brightness discrimination on CRF. Nevin reports that over 10 sessions of extinction, response probability decreased systematically for all birds, while accuracy remained about constant. Extinction of a sequential discrimination (Wolf, 1963) produces similar results.

In consideration of these data, it is probably better to conceive of the rate and accuracy levels in the early portions of the interval as reflecting specific schedule control of these response values, rather than a random (or uncontrolled) performance produced by prior extinction.

The parametric displacement of the within-cycle accuracy functions, in the face of increasing S+, S- disparity, lends support to this interpretation. This phenomenon could only result if schedule control over the pattern of responding was: a) relatively strong, and b) roughly equivalent at all temporal locations within the interval. As is most evident in DRL schedules, the absence of responding does not necessarily imply the absence of behavioral control. This argument is particularly compelling when response patterns in the first third of the interval are considered. In what might otherwise be considered a random performance, the percent correct shows a parametric reduction as S-/S+ values are increased.

The VI data adds little to the foregoing analysis. Although response rate gradients of the type used in the present experiment are to be expected in arithmetic VI schedules (Catania & Reynolds, 1968), the insensitivity of these gradients to changes in schedule deviation was unexpected.

The first 50 seconds of the interval closely replicate the FI data for all values of the VI, when we would in fact expect a noticeable redistribution of responding when a population of shorter reinforced intervals were introduced (Catania & Reynolds, 1968).

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