ALTERNATIVE REINFORCEMENT EFFECTS ON FIXED-INTERVAL PERFORMANCE

KENNON A. LATTAL AND SUSAN S. BOYER

WEST VIRGINIA UNIVERSITY

Pigeons' key pecks were reinforced with food on a fixed-interval schedule. Food also was available at variable time periods either independently of responding or for not key pecking (a differential-reinforcement-of-other-behavior schedule). The latter condition arranged reinforcement following the first pause of t seconds after it became available according to a variable-time schedule. This schedule allowed separation of the effects of pause requirements $\leqslant$ five-seconds and reinforcement frequency. The time spent pausing increased as the duration of the pause required for reinforcement increased from 0 to 30 seconds and as the frequency of reinforcement for pausing increased from 0 to 2 reinforcers per minute. Key pecking was more evenly distributed within each fixed interval with shorter required pauses and with more frequent reinforcement for pausing. The results complement those obtained with other concurrent schedules in which the same operant response was reinforced in both components.

Key words: fixed-interval schedules, DRO schedules, response-independent reinforcement, concurrent schedules, key pecking, pausing, matching, pigeons

Reinforcement resulting from contingencies other than those associated with a particular operant can affect the rate and temporal distribution of the operant responses under study. This idea has been expressed in general terms in the theoretical work of Herrnstein (1970) and Staddon and Simmelhag (1971). Herrnstein (1970) included R_o in his general matching equation to suggest how reinforcement from other than programmed sources might control behavior in competition with the operant responses for which reinforcement is arranged by the experimenter. Staddon and Simmelhag (1971) suggested that, for pigeons, such reinforcers as the opportunity to preen or to eat grain spilled from the hopper on the chamber floor control interim behavior that

competes with operant responses controlled by programmed schedules of reinforcement. Rachlin and Baum (1972) coined the term "alternative reinforcement" to describe reinforcement delivered either independently of responding or following pauses in responding (differential-reinforcement-of-other-behavior, DRO) when a schedule of reinforcement of key pecking operated concurrently.

Several studies suggest that the frequency and distribution of alternative reinforcement determines its competitive effects on other responses. Rachlin and Baum (1972) showed that key-peck response rates maintained by a variable-interval (VI) schedule were an inverse function of the frequency of alternative reinforcement delivered according to either a variable-time (VT) or a DRO schedule. Lattal and Bryan (1976) found that the addition of response-independent reinforcement at varying time periods changed the positively accelerated pattern of key-peck responding maintained by a fixed-interval (FI) schedule to a linear one. Overall response rates decreased with increases in VT reinforcement frequency. Zeiler (1976) also found that reinforcers delivered according to fixed-time (FT) or nominally equivalent DRO schedules reduced the rate of key pecking maintained by a FI schedule in proportion to the frequency of alternative re-

inforcement. With relatively frequent alternative reinforcement, responses were evenly distributed throughout the FI; with less frequent alternative reinforcement, positively accelerated responding occurred during the FI.

In each of these experiments, two operants, pecking and pausing, were reinforced concurrently. When alternative reinforcement is response-independent, pausing and pecking may be reinforced adventitiously at indeterminant frequencies. The DRO schedule defines more explicitly the pause necessary for reinforcement. Thus, the pause requirement functions as a change-over-delay (COD) in that alternative reinforcers that become available are delivered only when preceded by omission of the key-peck response for a predetermined duration. The DRO schedule may be arranged in either of two ways. Rachlin and Baum (1972) used a procedure first described by Nevin (1968). Under this procedure, reinforcers become available at varying time periods and, once available, are delivered following the first pause of the required duration. Required pauses are typically short in duration and several may occur between successive reinforcers. This procedure defines only the minimum pause interval necessary for reinforcement. Thus, longer pauses could be reinforced as would be the case if, for example, no responses occur for 30 sec prior to the availability of DRO reinforcement for pauses of at least 5 sec. In Zeiler's (1976) procedure each pause of the required duration was reinforced. This allowed more precise specification of the reinforced pause duration but confounded pause duration and reinforcement frequency since more frequent reinforcement occurred when shorter pauses were required.

The relation between required pause duration and alternative reinforcement is unclear. Zeiler (1976) found that FI response rates increased as the required pause duration for alternative reinforcement increased. However, as already noted, longer pauses were confounded by decreased alternative reinforcement frequency relative to that available during shorter pauses. Rachlin and Baum (1972) studied 0-sec (response-independent reinforcement) and 2-sec pause requirements and reported no systematic differences between the effects of the two. However, they did not directly compare these pause requirements in individual subjects.

These studies of alternative reinforcement suggest that the required pause between one response and delivery of the alternative reinforcement and the frequency of alternative reinforcement determine its behavioral effects. Reinforcement frequency and COD duration also are important determinants of concurrent schedule performance where the same response is controlled by different schedules (de Villiers, 1977; Herrnstein, 1970; Shull & Pliskoff, 1967). In the experiments reported here, the effects of these two variables during FI schedules were examined using a DRO schedule designed to reduce the confounding of pause duration and reinforcement frequency. Because different responses, key pecking and pausing, were reinforced concurrently, it was possible to compare the present results to those obtained from same-response concurrent schedules.

EXPERIMENT I

This experiment examined the relation between behavior during a FI schedule and the duration of a required pause for alternative reinforcement.

METHOD

Subjects

Four White Carneaux pigeons were maintained at 75% of free-feeding weights. Two were experimentally naive and two had a history of training on several reinforcement schedules.

Apparatus

An operant conditioning chamber 30 by 32 by 39.5 cm was used. A response key, operated by a force of .14N, was located on the midline of the work panel 22 cm from the floor. The key was transilluminated by a green light at all times except during reinforcement. Under all schedules, reinforcement was 3-sec access to mixed grain in a food hopper located behind a 5-cm square aperture 8.5 cm from the floor and on the midline of the work panel. The aperture was illuminated by a 7-W white light during reinforcement. A 7-W white houselight, located behind a translucent plastic cover in the lower right corner of the panel, provided general illumination in the chamber at all times except during reinforcement. White noise and a ventilating fan masked extraneous sounds. Electromechanical programming and

recording equipment was located in an adjacent room.

Procedure

After preliminary training, key-peck responding was stabilized under a FI 150-sec schedule. Then, alternative reinforcement was programmed concurrently on the average of once every 150 sec either independently of responding (VT) or after minimum specified pause requirements. These reinforcers were scheduled according to the constant probability distribution described by Fleshler and Hoffman (1962). The DRO schedule was analogous to a variable-interval schedule in which the reinforced "response" was a pause $\geq$ t-sec (cf. Nevin, 1968). A film programmer made reinforcement available at varying time periods. Once available, the reinforcer was delivered immediately if no response had occurred in the last t-sec or, if a response had occurred in that period, on completion of the first subsequent t-sec pause. The FI and alternative reinforcement schedules operated independently of one another. When the film programmer assigned a reinforcer, it was stopped until the end of food presentation. The FI clock continued to operate during this time. During FI reinforcement, the film programmer was stopped.

The pause requirement in the DRO schedule was a COD since it insured that key pecking was not temporally contiguous with DRO food delivery. However, reinforcers made available under the FI schedule were delivered following the first key peck after the FI lapsed. Thus it was possible for a pause followed by a single peck to be reinforced under the FI schedule. Since the delay was only between key pecking and reinforcement under the DRO schedule, it was labelled a one-way COD.

Previous studies of alternative reinforcement have used rate of key pecking as the only dependent variable. Since key pecking and pausing were reinforced concurrently, changes in both of these dependent variables were studied. Time spend pausing was defined as any period of nonresponding greater than or equal to 5 sec. This definition was established in a pilot study in which shorter pauses (e.g., 1 sec) were found to occur so frequently during the FI baseline that the measure was insensitive to experimental manipulations. Longer pauses (e.g., 10 sec) occurred so infre-

quently during the FI baseline that it also seemed unlikely that these pauses would be sensitive to experimental manipulations. The 5-sec value was selected because it was between these two extremes and seemed to occur with sufficient frequency to be useful as a dependent variable. Key-peck responses were recorded in successive sixths of the FI.

The value of the required pause varied between 0 and 30 sec. Table 1 gives the sequence of pause requirements and number of sessions at each. The 0-sec pause requirement is synonymous with the VT schedule, since pauses in responding were not required for reinforcement. Sequences included both gradual and abrupt changes in conditions from no required pauses and short pauses to long required pauses for alternative reinforcement. Condition changes were made only when the percentage of the session time spent pausing was stable. Stability required that three successive three-day means differed from the overall nine-day mean by less than ±5%. With three exceptions, a minimum of 15 sessions at each condition also was required. Sessions occurred five days a week and terminated after 45 reinforcers were delivered according to the FI schedule.

RESULTS

The effects of the different required pause durations on key-peck response rates and percent of session time spent pausing, are shown in Table 1. The means and ranges are for the last nine sessions at each condition. Key-peck response rates (number of responses/total session time) decreased slightly with increased required pauses in three of the four birds. Response rates of Bird 3269 increased under the 0-sec pause requirement and remained near the FI response rates under the other pause requirements. Introduction of the VT schedule substantially reduced the time spent pausing by each bird. Relative to pausing under the 0-sec condition, pausing increased up to the 5 to 10 sec pause requirement; at pause requirements longer than this, pausing did not show significant further increases. With pauses $\leq$ 5 sec, changing from shorter to longer pause requirements increased the percent time pausing and vice versa.

The quarter-life (Herrnstein & Morse, 1957) measure in Table 1 and the cumulative records in Figure 1 show another effect of adding

Table 1

Sequence of conditions, number of sessions at each condition, and data for each subject in Experiment I. The first condition for each subject was FI 150-sec. All subsequent conditions were FI plus variable DRO schedule with the pause requirements as indicated. Pause requirements are in seconds. Means and ranges are from the last nine sessions as each condition. Session duration was approximately 116 min.

Condition	Sessions	Key-peck response per minute		% Time pausing		DRO SR per minute		Quarter life
		$\bar{X}$	Range	$\bar{X}$	Range	$\bar{X}$	Range	
Bird 2039								
FI 150-sec	30	25	23-33	.57	.51-.65	—	—	.68
0.0	17	23	20-27	.44	.35-.51	.39	.38-.39	.32
0.2	30	25	20-30	.40	.27-.48	.43	.42-.44	.28
5.0	15	22	18-24	.54	.36-.56	.38	.35-.40	.54
2.0	19	24	19-30	.35	.34-.42	.41	.40-.43	.49
7.5	17	22	18-27	.57	.51-.63	.33	.29-.36	.65
20.0	15	16	14-20	.69	.63-.73	.32	.28-.37	.70
0.0	15	22	18-24	.46	.42-.51	.42	.41-.43	.47
5.0	9	16	22-32	.54	.49-.69	.35	.32-.38	.66
30.0	15	18	16-22	.67	.62-.70	.23	.20-.30	.67
Bird 3269								
FI 150-sec	55	36	32-46	.46	.41-.54	—	—	.60
0.0	15	67	57-76	.06	.05-.08	.40	.39-.40	.28
20.0	15	44	34-54	.43	.38-.46	.20	.14-.27	.52
10.0	15	38	33-42	.41	.36-.47	.24	.19-.31	.51
7.5	15	46	40-52	.41	.33-.46	.32	.29-.35	.60
5.0	30	37	32-42	.43	.38-.48	.38	.36-.42	.46
0.0	17	46	37-54	.10	.08-.11	.43	.42-.45	.27
5.0	15	36	29-43	.49	.41-.54	.39	.35-.41	.28
1.0	15	43	38-46	.13	.10-.14	.40	.39-.43	.29
2.0	44	33	27-39	.16	.10-.23	.40	.38-.45	.28
5.0	59	24	22-27	.53	.43-.64	.39	.37-.41	.31
Bird 7024								
FI 150-sec	40	30	25-33	.41	.33-.48	—	—	.52
0.0	28	34	29-37	.14	.10-.18	.39	.37-.43	.29
5.0	30	13	11-15	.84	.74-.88	.41	.39-.43	.27
20.0	22	15	14-17	.72	.68-.74	.29	.26-.32	.62
0.5	17	18	14-23	.66	.63-.79	.42	.41-.44	.28
5.0	16	13	10-17	.82	.73-.88	.42	.41-.44	.27
1.0	21	17	15-18	.55	.47-.60	.44	.42-.46	.28
0.0	22	22	20-26	.36	.26-.46	.40	.40-.41	.30
5.0	31	11	10-12	.82	.72-.87	.39	.37-.42	.32
1.0	47	17	16-20	.40	.34-.45	.41	.38-.44	.26
Bird 7477								
FI 150-sec	42	28	25-35	.34	.32-.41	—	—	.49
0.0	12	33	29-43	.18	.12-.21	.39	.38-.41	.27
0.2	30	34	30-40	.20	.09-.30	.42	.41-.45	.27
1.0	22	33	29-35	.26	.22-.33	.41	.32-.45	.26
5.0	32	21	19-23	.63	.57-.71	.40	.36-.43	.27
0.0	17	31	29-34	.26	.23-.29	.43	.34-.47	.25
5.0	15	21	19-24	.57	.52-.62	.40	.33-.42	.25
10.0	14	19	16-25	.57	.45-.65	.30	.27-.39	.50

alternative reinforcement. A quarter-life value of .25 indicates that one fourth of the responses occurred in the first quarter of the interval and values greater than this indicate increasing degrees of positive acceleration of responding. The measure was computed from an average of the number of responses in successive sixths of the FI over the last nine ses-
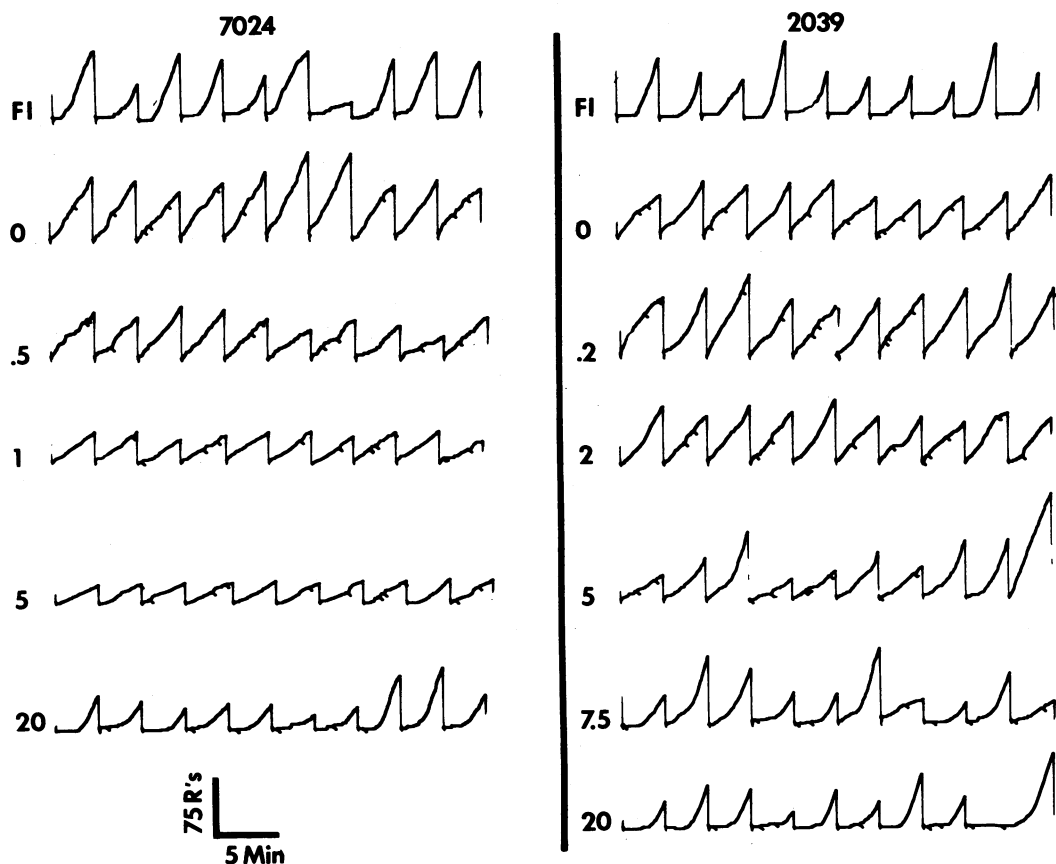
Fig. 1. Illustrative cumulative records under the different pause requirements (in sec), indicated to the left of the record, for Bird 7024 and 2039. The pen reset with each FI reinforcement. Deflections of the pen indicate DRO reinforcers. Each record depicts the 11th through 20th FIs for the last session of each condition.

sions of each condition. Response rates were markedly positively accelerated under the FI schedule and became more evenly distributed throughout the FI when the VT schedule (0-sec pause requirement) was added (cf. Lattal & Bryan, 1976). Two different response patterns occurred under the alternative reinforcement conditions and are illustrated in Figure 1. In one, long pauses after reinforcement were followed by high response rates; in a second, shorter pauses occurred throughout the interval. The former response pattern was more characteristic of longer required pauses while the latter occurred under the shorter required pauses. Changes from long to short pause requirements (e.g., Bird 2039 under 0-sec requirement after the 20-sec requirement) resulted in a reversal of response patterns in a manner generally consistent with this description. However, the value of the quarter life during the first and subsequent exposures to

the same delay value were not always identical.

Reinforcement frequency during the DRO schedule was relatively constant between 0 to 5 sec required pauses but decreased at pause requirements greater than 5 sec (see Table 1). The FI reinforcement frequency for all birds was constant between .38 and .39 reinforcers per minute during all pause requirements.

DISCUSSION

Alternative reinforcement delivered during fixed-interval schedules affected both the rate and temporal distribution of key pecking and the duration and temporal distribution of pauses in responding. Its effects were dependent on requiring pausing in key pecking and on the duration of the pause necessary for alternative reinforcement.

A primary consideration in using the DRO schedule described by Nevin (1968) was that

of decreasing the confound between the effects of change in alternative reinforcement frequency and pause requirements. The data in Table 1 illustrate its effectiveness. Relative to the 0-sec pause requirement, increasing the pause requirement up to 5 sec increased time spent pausing without appreciably changing the frequency of alternative reinforcement. Required pauses greater than 5 sec resulted in decreases in alternative reinforcement frequency.

Neither Zeiler (1976) nor Rachlin and Baum (1972) reported consistent differences between the effects of response-independent (VT) and response delayed (DRO) alternative reinforcement on key pecking. The present data show that FI response rates were higher and percent time spent pausing was lower during the VT alternative reinforcement condition. This was more marked at pause requirements greater than 5 sec. Rachlin and Baum studied only two pause requirements, and variations in pause requirements necessitated changes in reinforcement frequency in Zeiler's (1976) study.

The changes in FI response patterns were consistent with the earlier finding of Lattal and Bryan (1976) that positively accelerated FI response patterns become more equal throughout the interval by the addition of concurrent response-independent reinforcement. The occurrence of more evenly distributed key-peck responding during the FI when short pauses are required and positively accelerated rates of key-pecking when long pauses are required for alternative reinforcement also agrees with Zeiler's (1976) findings.

One problem encountered was measurement of the time spent pausing. The pause was defined as any period ≥ 5 sec without a key peck. Since the value of the required pause for reinforcement varied, it is possible that the absolute time spent pausing may not be reflected in the arbitrarily defined measure. However, as a relative measure it was quite useful because it was constant across the range of required pauses.

EXPERIMENT II

The effects of alternative reinforcement frequency on key pecking and pausing during a FI schedule were examined in the second experiment. Based on the results of the first experiment, periods of nonkey pecking ≥ 5 sec

both defined the measure of pausing and the alternative reinforcement requirement.

METHOD

Subjects

Three White Carneaux pigeons were maintained at 75% of their free-feeding weights. Each had a history of performance under FI schedules.

Apparatus

The apparatus was similar to that in the first experiment with one exception. The work panel of the chamber was modified to contain two 5-cm square apertures located 9 cm to either side of the midline and 8.5 cm from the floor. A food hopper was located behind each aperture. Grain was made available under the FI schedule from the left hopper and under the DRO schedule from the right hopper. This was done in an attempt to make peck- and pause-produced reinforcers more discriminable. However, a subsequent study revealed no performance differences when peck and pause-produced reinforcers were available from the same or different hoppers.

Procedure

After preliminary training, key-peck responding was maintained under a FI 300-sec schedule. Following this, a concurrent FI 300-sec DRO schedule was introduced. Reinforcers made available at varying time periods under the DRO schedule were delivered immediately if no response had occurred in the preceding 5 sec or, if a response had occurred in that period, on completion of the first subsequent 5 sec period without a key peck. Under the different conditions, DRO reinforcers were scheduled according to the constant probability distribution described by Fleshler and Hoffman (1962). Reinforcers made available under the FI schedule were delivered following either the first key peck after the FI lapsed or after the first such key peck not preceded by a pause ≥ 5 sec. The former relationship between FI reinforcement and pausing is the same as the one-way COD described in Experiment I. The latter relationship will be described as a two-way COD since a key peck was separated from DRO reinforcement by at least 5 sec and a pause of greater than or equal to 5 sec was separated from FI reinforcement by at least that duration.

Four frequencies of alternative reinforcement were used: 30 sec; 90 sec; 150 sec; and 600 sec. Each frequency was studied first using a one-way COD and, following a return to a FI 300-sec schedule (extinction, EXT, replaced the DRO schedule in the other component of the concurrent schedule), then under the two-way COD. The sequence of these conditions is shown from left to right in Figure 4. Most conditions were in effect for 12 sessions. The exceptions, under the one-way COD, were as follow (conditions in which FI 300-sec was in effect are labelled EXT): Bird 1140: 30 sec—36 sessions; 150 sec—26 sessions; 600 sec—19 sessions; EXT—32 sessions. Bird 1242: 30 sec—19 sessions; 150 sec—15 sessions; 600 sec—26 sessions. Bird 383: 90 sec—25 sessions; 150 sec—16 sessions; 600 sec—27 sessions; EXT—39 sessions. Under the two-way COD, Bird 383 was under the 30-sec condition for only seven sessions because its time spent pausing was almost 100% in each session.

Rates and distribution of key pecking and time spent pausing were measured as described in Experiment 1. Sessions were conducted five days a week and terminated when 20 FI reinforcers were obtained.
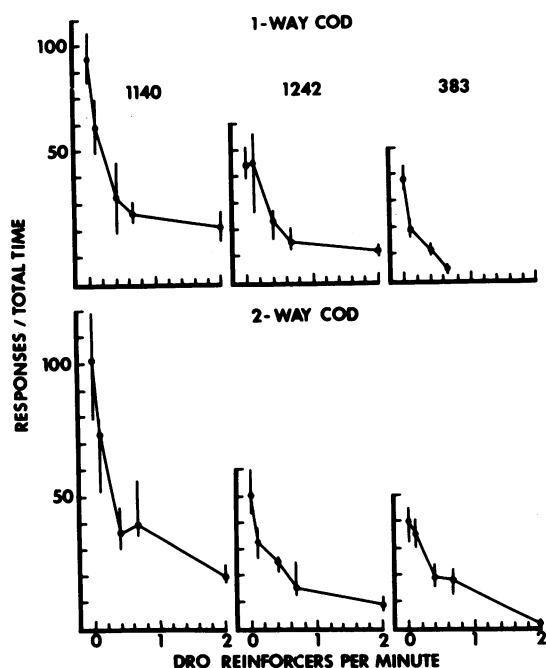
RESULTS

Figures 2 and 3 show the effects of alternative reinforcement frequency on key-peck response rates. Data points are the means of the last seven sessions at each condition. Figure 2 shows that key-pecking rates were highest when DRO reinforcers did not occur and lowest when DRO reinforcement was most frequent under both the one and two-way CODs. Response rates during successive sixths of the FI are shown in Figure 3. These rates were more nearly equal when alternative reinforcement was most frequent. As alternative reinforcement frequency decreased, key pecking nearer the end of the FI increased. Thus, positive acceleration of responding was decreased when alternative reinforcement was available because the high response rates near the end of the FI decreased.

The percent time spent pausing is shown for each of the last seven sessions at each condition in Figure 4. The horizontal dashed lines indicate the means of the seven data points. Time spent pausing was greatest when reinforcement for pausing was most frequent (DRO 30-sec) and was the least when reinforcement for pausing was omitted (EXT). The one-way and two-way COD's did not produce systematic differences in time spent pausing.

Figure 5 shows the relation between the logarithm of the ratio of time spent pausing to time spent pecking (total time *minus* time spent pausing) and the logarithm of the ratio of reinforcers delivered for pausing to reinforcers delivered for pecking under the FI schedule (cf. Baum, 1974). Time, rather than rate of key pecking, was chosen for analysis since it was the only common behavioral measure for the two schedules. Time spent engaged in one of two or more concurrently available schedules in at least as good an index of performance as is rate of a discrete response (e.g., de Villiers, 1977). Only data from the two-way COD were analyzed since the COD is necessary to compare these results to those from other concurrent schedules. The method of least squares was used to fit straight lines to the logarithmic data. The equations for these best-fit lines are shown in the lower right corner of each graph. For the combined data of all three animals (lower right graph), the slope of the lines was less than 1.0 and the intercept was negative.

Fig. 2. Means and ranges of key-peck responses per min during different frequencies of alternative reinforcement under the one- and two-way CODs.

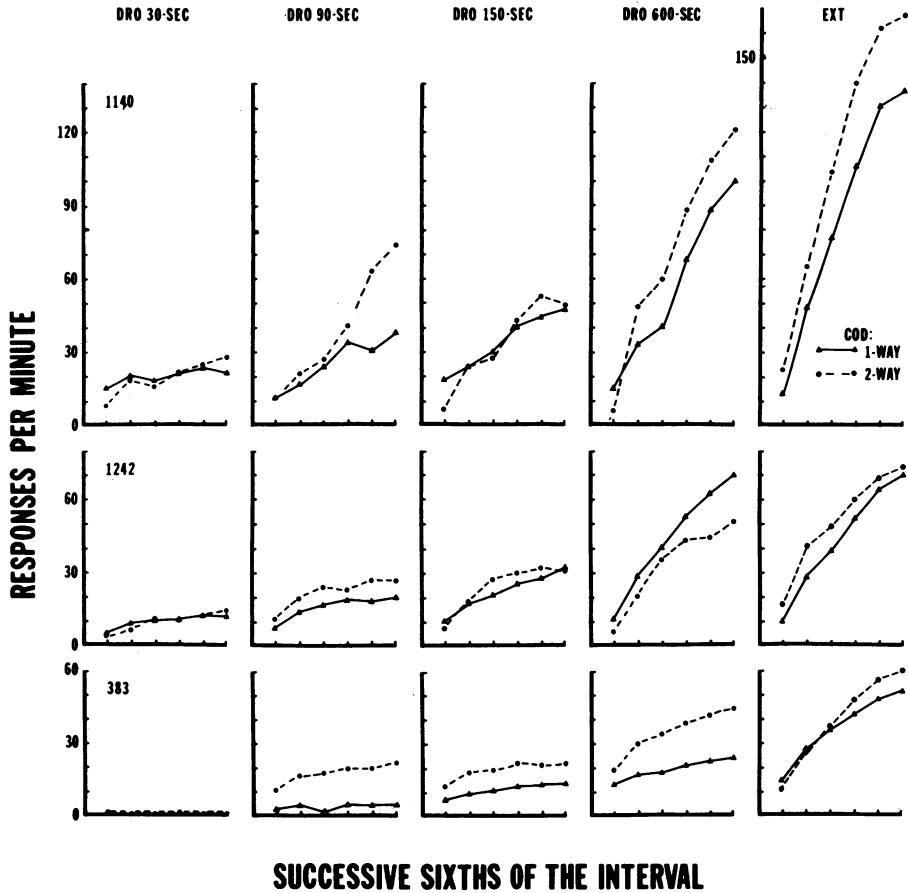**SUCCESSIVE SIXTHS OF THE INTERVAL**

Fig. 3. Key-peck responses per minute during successive sixths of each FI under the one and two-way CODs. The FI schedule alone is labelled "EXT" to indicate the elimination of alternative reinforcement.

DISCUSSION

Alternative reinforcement frequency strongly influenced the rate of key pecking and the time spent pausing within each session. In the first experiment response rate, time spent pausing, and frequency of alternative (DRO) reinforcement were all dependent variables influenced by the required pause requirement. The results of this second experiment show more clearly the effects of alternative reinforcement frequency since it was the independent variable. In contrast to previous studies (Zeiler, 1976, 1977) and to the first experiment, the pause requirement was constant throughout the changes in reinforcement frequency.

Response rates during the FI decreased as the pause requirement increased in Experiment 1. In the second experiment, response rates during FI increased as the frequency of alternative reinforcement decreased. The response rate increases found by Zeiler (1976) seem therefore to be due to changes in alternative reinforcement frequency and not to changes in the pause requirement.

GENERAL DISCUSSION

A number of studies report more or less precise mathematical relationships between reinforcement frequency and response rates under concurrent schedules (de Villiers, 1977). The present data bear on the appropriateness and generality of the matching relation as a way of describing the results of the concurrent reinforcement of pecking and pausing, on the nature of the COD, and on the response chosen for analysis.

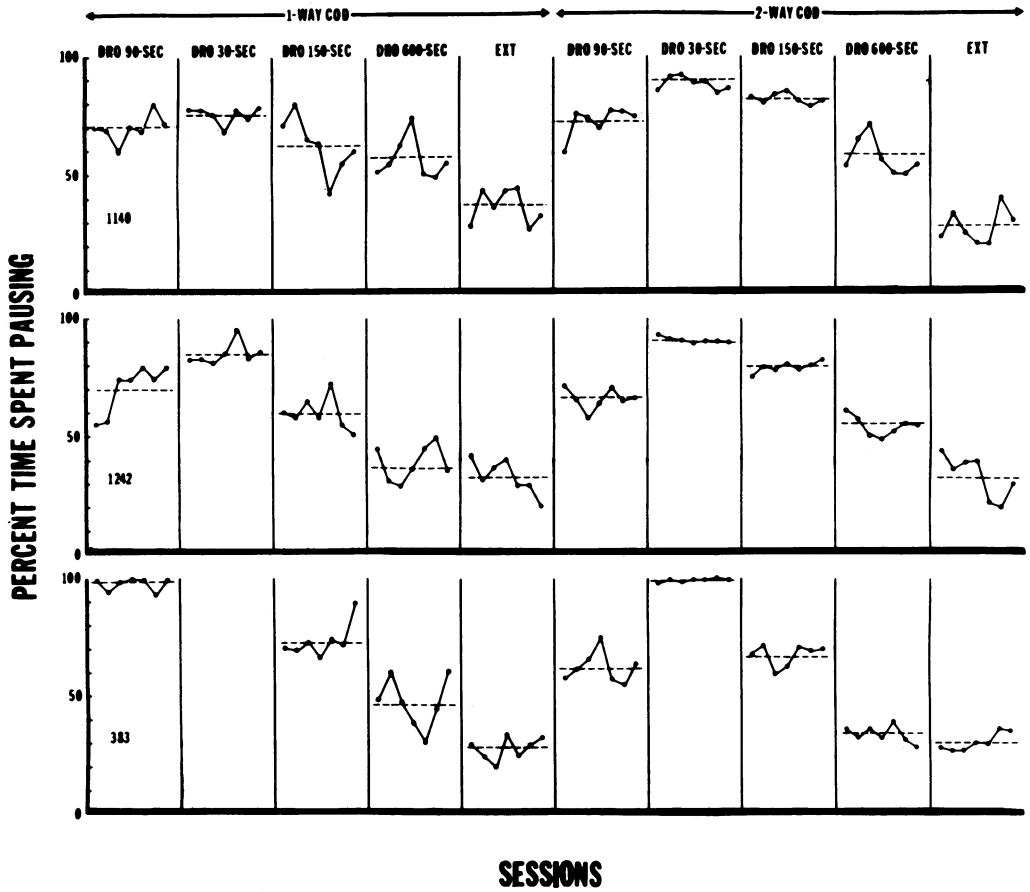Rachlin and Baum (1972) reported matching between reinforcement frequency and VI

Fig. 4. Percent of the total session time (approximately 100 min in duration) spent pausing during the last seven sessions at each condition under the one- and two-way CODs. The FI schedule alone is labelled "EXT" as in Figure 3.

response rate when alternative reinforcement at varying frequencies was programmed concurrently with the VI reinforcement schedule. Zeiler (1977) criticized the use of Rachlin and Baum's matching equations for such concurrent schedules of pecking and pausing on the grounds that response rate and reinforcement frequency are negatively correlated and totally interdependent in such schedules. This interdependency is only a problem when the pause requirement and reinforcement frequency covary as in Zeiler's (1976, 1977) procedure. In the procedure in Experiment II, a relatively short, fixed, pause duration was required in the presence of different frequencies of reinforcement. The interdependence of pecking and pausing under these conditions is no different from that which occurs in concurrent schedules with the same operant response (e.g.,

key pecking) in both components. There, increasing the amount of time spent responding on one operandum decreases the rate of reinforcement associated with the second operandum in an analogous manner to that which occurs under the concurrent schedules in the present second experiment.

The results of variations in the frequency of DRO reinforcement during the two-way COD condition in Experiment II are similar to those obtained using other concurrent schedules. The work most closely related to the present schedule is that involving concurrent FI VI schedules of key pecking (Lobb & Davison, 1975; Nevin, 1971; Trevett, Davison, & Williams, 1972), since only the operant in the VI component differed between this experiment and the others. In general, the ratios of time alloted to each schedule were simi-
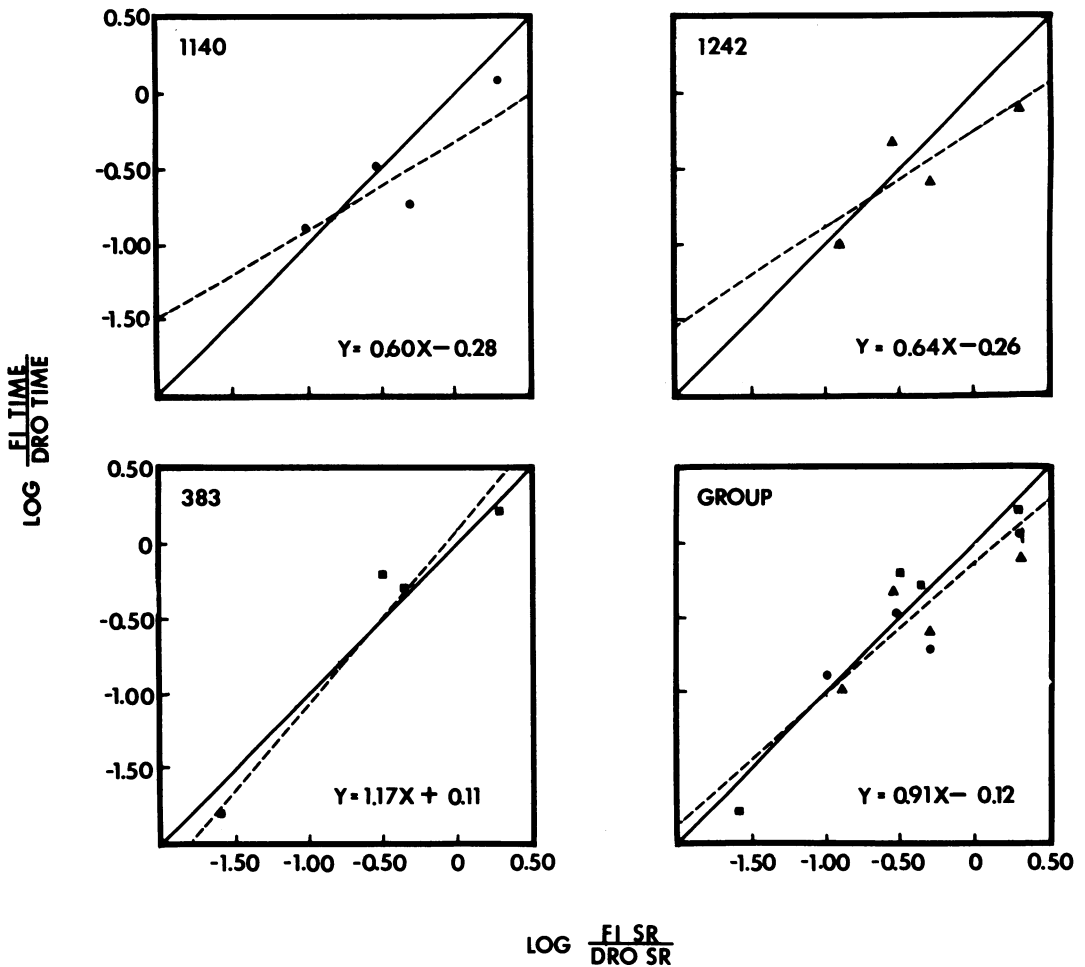
Fig. 5. Logarithmic ratios of time spent pausing to that spent pecking as a function of the logarithmic ratios of reinforcers delivered for pausing to reinforcers delivered for pecking for each bird.

lar to those attained under concurrent FI VI schedules by Lobb and Davison (1975). The general relation between time allocated to the two schedules (T) and the number of reinforcers obtained on each schedule (R) during a session was described by Lobb and Davison (1975) as:

$$\frac{T_1}{T_2} = c \left(\frac{R_1}{R_2}\right)^a. \tag{1}$$

They found that the equation:

$$\frac{T_1}{T_2} = .59 \left(\frac{R_1}{R_2}\right)^{.69}. \tag{2}$$

described the time allocation data of their experiment and that of Trevett et al. (1972). By comparison, the present time allocation data

from Experiment II are described by the equation:

$$\frac{T_1}{T_2} = .76 \left(\frac{R_1}{R_2}\right)^{.91}. \tag{3}$$

The value of c and a in the above equations respectively are the antilog of the logarithmic intercept and the slope of the regression equation for the group data in Figure 5. The value of c suggests that the group data are biased toward the DRO schedule. Since Lobb and Davison showed that pigeons are biased toward VI during concurrent FI VI schedules, it is not possible to isolate whether the bias was caused by the variable interreinforcer intervals during the DRO schedule, by the absence of a peck requirement, or by some combination of the two. Slope (a in Equation 1

above) values of less than 1.0 appear to be the rule rather than the exception when data are plotted on log ratio coordinates (Lobb & Davison, 1975; Myers & Myers, 1977). These results suggest further generality of the matching relation obtained under schedules involving a single operant response to schedules involving the concurrent reinforcement of pecking and pausing in responding.

As noted previously, the pause requirement functions as a change-over-delay between a key-peck response and delivery of alternative reinforcement. Shull and Pliskoff (1967) found that rats spent increasingly more time in the concurrent schedule component associated with more frequent brain stimulation reinforcement (VI 1-min versus VI 3-min) as the COD requirement increased. A similar but more markedly negatively accelerated function was obtained in Experiment I between pause requirement and time spent pausing. The two-way COD often controlled higher FI response rates than did the one-way COD (Figures 2 and 3). This effect probably is attributable to the requirement that, under the two-way COD, two key pecks had to occur within 5 sec of one another for FI reinforcement to occur. The reinforcement of short interresponse times increases their frequency and this change is reflected in the response rates (e.g., Morse, 1966).

The COD is usually considered to be a necessary condition for describing concurrent schedule performance in terms of the general equations developed by Herrnstein (1970). Zeiler (1976, 1977) used only a one-way COD in his studies of concurrently available FI and DRO schedules. Therefore, it was at least possible in principle for a peck reinforcer to follow a pause in responding. This could adventitiously strengthen "pause-peck" sequences and thereby lower response rates. Rachlin and Baum (1972) do not specify whether they used a one or two-way COD. The two-way COD used here eliminated this potential confound.

The data in Figures 2 and 5 show that overall FI response rates decreased and time spent pausing increased as the frequency of alternative reinforcement increased. These findings suggest that FI response rates were controlled by the relative reinforcement frequency provided by the FI schedule. An alternative interpretation is that the FI rate decreases were an induction effect resulting from the increased amount of time spent pausing. However, an account in terms of pause-peck interaction is not tenable since Lobb and Davison (1975) found a similar effect on FI key peck responding when key pecking was reinforced concurrently under a VI schedule.

REFERENCES

Baum, W. M. On two types of deviation from the matching law: Bias and undermatching. *Journal of the Experimental Analysis of Behavior*, 1974, 22, 231-242.

de Villiers, P. Choice in concurrent schedules and a quantitative formulation of the law of effect. In W. K. Honig & J. E. R. Staddon (Eds.), *Handbook of operant behavior*. Englewood Cliffs, N.J.: Prentice Hall, 1977.

Fleshler, M., & Hoffman, H. S. A progression for generating variable-interval schedules. *Journal of the Experimental Analysis of Behavior*, 1962, 5, 529-530.

Herrnstein, R. J. On the law of effect. *Journal of the Experimental Analysis of Behavior*, 1970, 13, 243-266.

Herrnstein, R. J., & Morse, W. H. Effects of pentobarbital on intermittently reinforced behavior. *Science*, 1957, 125, 929-931.

Lattal, K. A., & Bryan, A. J. Effects of concurrent response-independent reinforcement on fixed-interval schedule performance. *Journal of the Experimental Analysis of Behavior*, 1976, 26, 495-504.

Lobb, B., & Davison, M. C. Performance in concurrent interval schedules: A systematic replication. *Journal of the Experimental Analysis of Behavior*, 1975, 24, 191-197.

Myers, D. L., & Myers, L. E. Undermatching: A reappraisal of performance on concurrent variable-interval schedules of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1977, 27, 203-214.

Morse, W. H. Intermittent reinforcement. In W. K. Honig (Ed.), *Operant behavior: Areas of research and application*. New York: Appleton-Century-Crofts, 1966.

Nevin, J. A. Differential reinforcement and stimulus control of not responding. *Journal of the Experimental Analysis of Behavior*, 1968, 11, 715-726.

Nevin, J. A. Rates and patterns of responding with concurrent fixed-interval and variable-interval reinforcement. *Journal of the Experimental Analysis of Behavior*, 1971, 16, 241-247.

Rachlin, H., & Baum, W. M. Effects of alternative reinforcement: Does the source matter? *Journal of the Experimental Analysis of Behavior*, 1972, 18, 231-241.

Shull, R. L., & Pliskoff, S. S. Changeover delay and concurrent schedules: Some effects on relative performance measures. *Journal of the Experimental Analysis of Behavior*, 1967, 10, 517-527.

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

Trevett, A. J., Davison, M. C., & Williams, R. J. Performance in concurrent interval schedules. *Journal*

of the Experimental Analysis of Behavior, 1972, **17**, 369-374.

Zeiler, M. D. Positive reinforcement and the elimination of reinforced responses. *Journal of the Experimental Analysis of Behavior,* 1976, **26**, 37-44.

Zeiler, M. D. Elimination of reinforced behavior: Intermittent schedules of not-responding. *Journal of the Experimental Analysis of Behavior,* 1977, **27**, 23-32.