EFFECTS OF ALTERNATIVE REINFORCEMENT SOURCES: A REEVALUATION

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The effects of two alternative sources of food delivery on the key-peck responding of pigeons were examined. Pecking was maintained by a variable-interval 3-min schedule. In the presence of this schedule in different conditions, either a variable-time 3-min schedule delivering food independently of responding or an equivalent schedule that required a minimum 2-s pause between a key peck and food delivery (a differential-reinforcement-of-other-behavior schedule) was added. The differential-reinforcement-of-other-behavior schedule reduced response rates more than did the variable-time schedule in most instances. The delay between a key peck and the next reinforcer consistently was longer under the differential-reinforcement-of-other-behavior schedule than under the variable-time schedule. Response rates and median delay between responses and reinforcers were negatively correlated. These results contradict earlier conclusions about the behavioral effects of alternative reinforcement. They suggest that an interpretation in terms of response-reinforcer contiguity is consistent with the data.

Key words: alternative reinforcement, variable-time schedule, variable-interval schedule, response-reinforcer contiguity, conjoint schedules, concurrent schedules, key peck, pigeons

In 1972 Rachlin and Baum asked whether the source of alternative food delivery, available concurrently with a variable-interval (VI) schedule of food reinforcement of key pecking, mattered in determining response rates. Two sources were compared: Alternative reinforcers occurred either independently of key pecking according to variable-time (VT) schedules or they were arranged independently of key pecking but not within 2 s of a key peck (a tandem VT differential-reinforcement-of-other-behavior [DRO] schedule). They described these two sources of reinforcement as undelayed and delayed, respectively; hereafter, we refer to them as VT and DRO conditions. Of the results, they concluded (a) that "regardless of how the alternative reinforcement occurred . . . it produced the same effect on the concurrent VI performance" (Rachlin & Baum, 1972, p. 237) and (b) that in those conditions "where response-independent reinforcement was simply superimposed on ongoing responding . . . there must have been

occasional instances of a response immediately preceding a response-independent reinforcement. These reinforcements could have increased the rate of responding, just as they would have if they were response-dependent. If the only effect of [the alternative reinforcer] on responding was to provide occasional additional response-dependent reinforcements, however, the pigeon's rates of responding would have increased . . . and not decreased, as they actually did. The more response-independent reinforcement, the lower the rate of pecking—exactly the opposite of what one would expect if response-independent reinforcements were adventitiously reinforcing key pecking" (Rachlin & Baum, pp. 237-238).

Rachlin and Baum went on to note that "whereas the undelayed reinforcements must *often* have coincided with key pecks, the delayed reinforcements produced no greater decrease in key pecking" (1972, p. 238; *italics added*). These results have been offered as evidence against a principle of reinforcement based on temporal contiguity between responding and reinforcement, which would predict lower response rates in the DRO than in the VT condition (Rachlin & Baum, 1972; Williams, 1983).

Because of the theoretical significance of the results, the Rachlin and Baum experiment warrants further examination in terms of both

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its experimental design and the generality of the effects. In their study, 6 subjects were exposed to either the VT or the DRO conditions, but not to both. Two subjects were exposed to the VT and the DRO conditions alone, without exposure to a VI condition in which the alternative reinforcers were response dependent. Within-subject comparison of the effects of the VT and DRO conditions was minimal, thus limiting the conclusion that these two conditions affected responding similarly. Furthermore, in comparing the effects of the VT and DRO conditions for the 2 subjects exposed to both conditions, Rachlin and Baum stated that "Comparisons of the effects of delayed and undelayed free reinforcement on the same subject can be made for S-1 and S-2. . . . In Figure 1, the two curves for each of these birds suggest no striking differences in the effects of the two procedures" (p. 236). Several observations qualify this statement. First, the curves for S-1 and S-2 in their Figure 1 represented Conditions II and III of their study, in which both the amount of reinforcement and the reinforcement frequencies were varied, respectively. Second, their Figure 1 showed that at the .5 relative reinforcement-A value, where both amount and frequency of reinforcement were the same for both subjects, response rates were different for the VT and DRO conditions, with higher rates in the VT condition. Third, the claim that contiguity between responses and food presentations occurred often under the VT condition was unsubstantiated because data on how closely in time response-independent food presentations were to key pecks (or other responses) were not reported.

Other experiments have not confirmed the general findings reported by Rachlin and Baum. Zeiler (1976), comparing rates of responding under conjoint fixed-interval (FI) 3-min DRO *t*-s and FI 3-min fixed-time (FT) *t*-s schedules, reported that "Except at the lowest points, a given reinforcement frequency earned via the DRO component reduced response rate more than did that earned from the FT component" (p. 41). Henton and Iversen (1978) compared the effects on rats' VI-schedule-maintained lever pressing of an alternative source of food delivered according to either a VT schedule or a VT schedule with the additional requirement that a 1-s pause precede each reinforcer (a DRO schedule). The DRO schedule reduced the probability of a lever press more than did the VT schedule.

The apparent lack of congruence in results under related, but not identical, conditions between the experiments of Rachlin and Baum and those of Zeiler and of Henton and Iversen, in the context of the potential theoretical significance of Rachlin and Baum's findings, was the impetus for the present experiment. We replicated three of Rachlin and Baum's conditions relevant to their conclusions concerning the absence of differences in the behavioral effects of adding DRO and VT food delivery schedules to a VI schedule and about the temporal relations between responses and reinforcers under the VT conditions. In one condition, two VI schedules arranged food presentations for pecking on a single key. In another condition, a VT schedule was superimposed on a VI schedule operating on a single key. In the third condition, the contingency was the same as in the second condition, except that a 2-s pause in responding was required after the VT interval had elapsed. Obtained delays between VT or DRO food deliveries and key pecking under the latter two conditions were of particular interest.

METHOD

Subjects

Four White Carneau pigeons were maintained at approximately 80% of their free-feeding body weights. Each except Pigeon 4600 was experimentally naive at the beginning of the study; Pigeon 4600 had been used in a pilot study that included some of the conditions used in the present study.

Apparatus

Two experimental chambers were used. Each had dimensions of 30.5 by 32.5 by 37.7 cm and contained two 2.5-cm-diameter response keys, only one of which was used in each chamber. In one chamber the response key, located 23.2 cm above the chamber floor and 7.0 cm from the right wall, was transilluminated by a red light. The chamber was illuminated by a 5-W white houselight located behind an aperture (4.0 by 3.8 cm) 3.1 cm above the chamber floor. In the other chamber the response key, transilluminated by a blue light, was located 24.3 cm above the chamber floor and 8.3 cm from the left wall. The keys in both chambers were operated by a minimal force of 0.18 N. The chamber was illuminated by a 7-W white houselight from an aperture

(4 by 4 cm) 3 cm above the chamber floor. In each chamber, the food hopper was located behind an aperture 8 cm from the chamber floor. During food presentation the hopper was raised and illuminated for 4 s and the house-light and keylight were turned off. Ventilation fans masked extraneous sounds in each chamber. A PDP® 8a computer using Super-SKED® software controlled the experiment from an adjacent room.

Procedure

The key peck of each naive pigeon was hand-shaped. The experienced pigeon was placed directly on the first training condition. Key-peck responding was stabilized first under a VI 1-min schedule and then under a VI 1.5-min schedule.

Three subsequent conditions then were studied in which food delivery was arranged from two sources (schedules). In each condition, the response key was illuminated at all times except during food presentation. The scheduling of all food presentations was determined by the constant probability distribution described by Fleshler and Hoffman (1962) using two identical but independent distributions consisting of 24 intervals ranging from 3.65 to 759.40 s, with a mean interval of 184.38 s (hereafter described as 3 min). The three conditions were as follows:

Conjoint VI 3 min VI 3 min (VI condition). Two identical VI 3-min schedules were scheduled conjointly. Under this schedule reinforcers delivered according to either schedule depended on responses to the same key (see Catania, Deegan, & Cook, 1966). If food became available on one VI schedule during presentation of food on the other VI schedule, the former food delivery was withheld until one key peck had occurred after the end of the hopper presentation on the latter schedule.

Concurrent VI 3 min VT 3 min (VT condition). Two schedules, a VI 3 min and a VT 3 min, were in effect concurrently. The VI schedule ensured that food delivery occurred following a key peck when the VI interval had elapsed. The VT schedule delivered food independently of key pecking. When food presentation on the VT component became available during food presentation arranged by the VI component, the VT food delivery occurred immediately after the end of the hopper presentation on the VI component, independently of key pecking. Thus, response-independent

food delivery could occur in close temporal proximity to either VI-arranged reinforcers or a key peck.

Conjoint VI 3 min tandem VT 3 min DRO ≥ 2 s (DRO condition). Two schedules, a VI 3 min and a tandem VT 3 min DRO ≥ 2 s, were scheduled conjointly. Reinforcers under the DRO schedule became available on the average of once every 3 min. These reinforcers were delivered *only* if there had been no key peck within the previous 2 s (see Nevin, 1968). If a key peck occurred within 2 s of a scheduled food presentation, its delivery was postponed until 2 s had elapsed without a key peck. Thus, there was a minimum pause requirement of 2 s between DRO-scheduled food presentations and the last key peck. Pauses could exceed 2 s, however. For Pigeon 2315, when this condition was repeated, the minimum pause requirement was changed to 6 s. This was necessary because response rates for this pigeon were particularly low.

Table 1 shows the sequence of conditions for each subject. Each pigeon's responding was maintained first under the conjoint VI 3-min VI 3-min schedule. Subsequently, this baseline schedule was alternated across conditions with the VT and the DRO conditions. The VT and the DRO conditions were repeated twice for Pigeons 4573, 4600, and 5371; for Pigeon 2315, the 2-s pause requirement in the first DRO condition was replaced by one of 6 s in the second.

Each condition remained in effect for each pigeon for a minimum of 25 sessions (except for Pigeon 2315 during the first VI condition) until responding stabilized. Stability was defined by six consecutive sessions in which the mean of the first and last 3 days did not differ by more than 3% from the 6-day mean. The only exception was Pigeon 2315 during the first VI condition of the experiment. Sessions were conducted 6 days per week and each session lasted 60 min.

RESULTS

Table 1 provides the mean absolute response rates for the last six sessions of each condition. For each subject, four comparisons can be made of the DRO and VT conditions: The effects of the first and second DRO condition can be compared to both the first and second VT conditions. Of these 16 comparisons, the mean response rate was higher in the

Table 1

For each pigeon, sequence of conditions, number of sessions, mean number of VI and VT or DRO reinforcers, and mean absolute response rates during the last 6 days of each condition.

Subject	Conditions	Number of sessions	Mean number of reinforcers		Mean/median absolute response rates (range)
			VI	VI, VT, or DRO	
5371	VI	40	17.8	18.7	51.89/50.80 (46.53–59.31)
	DRO	29	18.2	17.7	23.69/23.68 (21.77–26.73)
	VI	27	18.3	16.8	40.21/40.58 (35.12–43.50)
	VT	40	19.0	19.3	30.81/29.96 (29.13–34.19)
	VI	25	17.3	18.5	39.67/37.89 (36.53–43.24)
	DRO	25	16.7	17.2	28.39/28.36 (26.94–30.28)
	VI	25	18.2	19.2	41.29/41.21 (38.70–43.76)
	VT	25	18.3	19.0	34.39/34.88 (30.41–37.28)
	VI	27	18.3	17.0	37.65/37.36 (30.64–44.48)
4573	VI	45	17.2	19.2	41.48/41.50 (38.51–44.51)
	DRO	36	18.2	18.2	41.23/41.09 (39.96–42.81)
	VI	24	18.3	19.0	58.08/58.80 (51.71–62.37)
	VT	25	17.5	17.8	47.64/46.97 (44.66–53.49)
	VI	25	18.2	17.5	64.91/65.07 (61.51–67.73)
	DRO	28	17.7	17.7	45.38/45.24 (43.62–47.86)
	VI	25	17.0	17.2	62.70/62.20 (60.17–66.04)
	VT	25	17.8	19.0	59.16/58.87 (56.60–62.83)
	VI	25	17.7	16.8	73.18/72.65 (69.93–77.34)
2315	VI	14	17.7	17.3	28.48/28.99 (24.94–31.17)
	VT	32	17.2	18.7	14.09/14.16 (12.02–16.30)
	VI	19	18.5	16.7	17.75/17.86 (16.64–18.60)
	DRO (2 s)	30	17.3	17.2	13.95/13.98 (13.51–14.25)
	VI	39	18.5	18.2	13.65/13.84 (12.01–14.97)
	DRO (6 s)	23	15.8	17.2	9.29/9.42 (7.39–10.43)
	VI	25	17.2	17.8	10.28/10.19 (9.93–10.87)
	VT	26	17.5	19.0	12.85/12.92 (11.33–14.02)

Table 1 (*Continued*)

Subject	Conditions	Number of sessions	Mean number of reinforcers		Mean/median absolute response rates (range)
			VI	VI, VT, or DRO	
4600	VI	25	18.0	18.7	20.05/20.15 (18.81–20.93)
	VI	25	16.7	17.7	73.05/70.12 (52.49–91.77)
	DRO	25	18.2	18.8	47.89/48.17 (40.89–54.45)
	VI	25	17.8	19.5	86.04/87.01 (79.65–92.27)
	VT	27	18.2	18.2	56.29/55.35 (48.15–64.40)
	VI	25	16.3	18.0	93.56/96.24 (85.55–100.09)
	DRO	28	18.7	17.0	22.66/22.44 (21.38–24.12)
	VI	25	18.0	16.5	71.88/72.34 (64.75–76.81)
	VT	25	18.2	17.3	46.55/46.80 (39.67–51.39)
	VI	29	18.0	17.5	57.82/58.42 (53.00–62.06)

VT condition than in the DRO in 14 comparisons. The differences were slight in three (Pigeon 5371: second DRO compared to first VT; Pigeon 4573: second DRO compared to first VT; and Pigeon 2315: first DRO compared to first VT). The two comparisons that yielded higher DRO rates were Pigeon 2315: first DRO compared to second VT (a difference of less than one response per minute) and Pigeon 4600: first DRO compared to second VT (a difference of 1.34 responses per minute). Comparing only the mean rates during first DRO with the first VT and the second DRO with the second VT condition, the differences between DRO and VT were greater during the second comparison for 2 of the 3 subjects (Pigeons 4573 and 4600; this comparison is questionable for Pigeon 2315 because the DRO value was increased in the second DRO condition). Similar results were obtained when median response rates were compared: Of the 16 comparisons of median rates in the VT and DRO conditions, in 14 the rates were higher in the VT condition (see Table 1).

Figure 1 summarizes the relation between mean absolute response rates over the last 6 days of each condition and median obtained delays during the last 6 days of each condition.

Response rates generally decreased as obtained delays increased. Because briefer median delays occurred during the VT conditions (cf. Figures 2 and 3 below) than during the DRO conditions, the data points for the VT conditions (closed circles) are always to the left of those for the DRO conditions (open circles).

The distributions of obtained delays between the last key peck and food delivery during the two VT conditions are shown in Figure 2. Each bar shows the total number of such delays for the last six sessions of each condition. In each of these sessions there were approximately 18 response-independent reinforcers (range, 13 to 21). The data are presented in 0.5-s intervals (bins), except for the first (≤ 0.10 -s), second (0.11–0.50-s), and last (> 2.0 -s) intervals. The distributions during the first and second VT conditions did not differ systematically from one another. An average of about one reinforcer per session was within 0.10 s of a key peck. The only exception was Pigeon 4573 during the second VT condition, in which there was an average of 2.66 reinforcers per session within 0.10 s of a key peck. Most of the obtained delays for each subject were between 0.11 and 2.0 s. Averaged across subjects, about four reinforcers per session occurred between 0.11 and 0.5 s after a

Fig. 1. Mean responses per minute, averaged over the last six sessions of each condition, as a function of the median obtained delay between the last response and VT food presentations (closed circles) or DRO food presentations (open circles). Medians were obtained from the last six sessions of each condition.

key peck, about eight reinforcers occurred between 0.51 and 2.0 s after a key peck, and about five reinforcers occurred after delays in excess of 2 s. The minimum obtained delay under the DRO schedule was 2.0 s. Distributions for the DRO obtained delays are not included because more than 95% of these delays were between 2.0 and 2.5 s. The median delays preceding DRO reinforcers always were longer than those preceding VT food presentations and, in most instances, the ranges of the obtained delays for the two conditions were nonoverlapping. The exception was Pigeon 2315 during the 2-s DRO requirement.

Figure 3 shows the obtained delays for successive VT and DRO food presentations for each pigeon. Each data point is the median of the last 6 days of each condition for a given food presentation location. That is, the data point for food presentation Number 1 is the median obtained delay for that food presentation number considered over the last six sessions of the condition. In all cases except for Pigeon 2315, obtained delays between key pecks and successive VT food presentations were consistently shorter than those under the DRO conditions. Except for those of Pigeon 2315, the median obtained delays under the VT condition were shorter than those under

the DRO condition. As also indicated in Figure 2, most of the delays in the VT condition ranged between 0.5 and 2.0 s. Under both VT conditions, the obtained delays of Pigeon 2315 averaged about 2.0 s (see Figure 3). Obtained delays for successive DRO-scheduled reinforcers were greater than or equal to 2.0 s under the two DRO conditions.

Although response rates during each VI condition were stable prior to introducing the next VT or DRO condition, the absolute response rates varied across VI conditions (see Table 1). Therefore we also compared response rates during the last 6 days of each condition, normalized relative to the average of the last six sessions of the VI conditions preceding and following each condition shown. The normalized response rates were obtained by dividing the response rate of each of the last six sessions of the VT and DRO conditions by the average response rate of the six stable VI sessions immediately preceding and following them, and then subtracting 100 from the result. Figure 4 shows these results. For each pigeon, both the DRO and VT conditions reduced response rates relative to the VI condition (0 on the y axis). During the first comparison between DRO and VT, the relative response rates of Pigeon 5371 were lower in the DRO than in the VT condition. For Pigeon 4573, both DRO and VT reduced relative response rates equally; during four of the last six sessions, the normalized response rates of Pigeon 4600 were slightly lower in the DRO condition than in the VT condition. For Pigeon 2315 the VT yielded lower relative rates of responding than did the DRO. This reversal in the anticipated effects of the two conditions for this subject may be attributed in part to the atypically low response rates in all conditions by this subject. These low rates magnify small differences in relative rate; therefore the validity of the comparison seems questionable. During the second comparison, the DRO schedule reduced the relative rates of each pigeon proportionally more than did the VT schedule. The normalized response rates shown in Figure 4 reflect the fluctuations in the baseline rates. In the case of Pigeons 4573 and 4600 during the first comparison, these fluctuations also obscure absolute mean response rate differences between the VT and DRO conditions (with lower rates in the DRO condition) shown in Table 1.

Fig. 2. Number of obtained delays of different durations. The first bin shows values <0.10 s and the last bin, values >2 s.

Table 1 also shows that the mean number of food presentations under the VT, VI, and DRO schedules was approximately equal for each pigeon. When the DRO value was changed to 6 s for Pigeon 2315, the number of food presentations remained unchanged.

DISCUSSION

Three findings of this experiment invite comment: the comparison between the effects of the DRO and VT conditions on overall response rates, the obtained delays between responses and reinforcers, and the relation between response rate and obtained delay.

Results of the comparison of alternative reinforcement arranged after a period of non-responding (DRO condition) and such reinforcement arranged independently of responding (VT condition) within individual subjects lend little support to the conclusion of Rachlin and Baum (1972) stated in the first quote in the first

paragraph of this paper. Response rates in general were lower when the DRO schedule was in effect. These results are similar to those obtained by Zeiler (1976), but Zeiler's effects were obtained with longer DRO requirements (the shortest DRO value that he studied was 10 s).

The response-reinforcer delay data indicate that the number of instances in which responses immediately preceded response-independent reinforcers were few. Even in the absence of a precise definition of "immediate," Rachlin and Baum's (1972) suggestion that there were *often* instances in which a response-independent reinforcer coincided with key pecks was not supported by the present data. In the VT conditions for different subjects, two to eight reinforcers per session delivered independently of responding occurred within 0.5 s of a key-peck response. The remaining response-independent reinforcers in the session occurred after delays greater than 0.5 s. Ob-

Fig. 3. Median obtained delays during successive food presentations during the first (top graph for each bird) and second (bottom graphs for each bird) comparisons of the VT (T) and DRO (D) conditions. Filled circles connected by dashed lines represent the DRO, and filled squares connected by solid lines represent the VT. See text for details of how the data were calculated.

Fig. 4. Relative response rates during each of the last six sessions of each condition during the first (left graphs) and second (right graphs) comparisons of the VT (labeled T and shown by solid lines and filled squares in the Figure) and DRO (labeled D and shown by dashed lines and filled circles in the Figure) conditions. The first and second

RELATIVE RESPONSE RATE

SESSIONS

exposures to each condition are shown, respectively, in the graphs on the left and right for each pigeon (rows). Response rates are expressed as percentage of the average of the VI conditions immediately preceding and following each condition shown.

tained delays in excess of 0.5 s usually reduce response rates (Sizemore & Lattal, 1978), a finding consistent with the present results.

The relation between response-reinforcer delay and response rates was illustrated in two ways in the present data. First, the DRO schedule yielded lower response rates than did the otherwise equivalent VT schedule. The only exception was for Pigeon 2315 during the first comparison of these two conditions, where the delay values in VT exceeded or equaled those in the DRO condition. Second, the data summarized in Figure 1 indicate a characteristic delay gradient; longer obtained delays were correlated with lower response rates. The curve appears rough because the delay time scale on the x axis is compressed. The correlational nature of this relation in the case of the VT conditions is acknowledged (cf. Sizemore & Lattal, 1978); however, the fact remains that median response-reinforcer delay accurately predicts response rates. In the case of DRO conditions, the nominal delay requirement determined the rate of responding.

Rachlin and Baum (1972) suggested that an account of the effects of response-independent reinforcers based on temporal response-reinforcer contiguity might predict an increase in responding when a conjoint VI VI schedule is changed to a concurrent VI VT because of the "occasional instances of a response immediately preceding a response-independent reinforcement" (p. 237). This suggestion appears to hold only if a number of VT reinforcers were contiguous with key pecks, a result that the present data do not support. Such an account would predict a decrease in responding when the schedule is changed to concurrent VI VT to the extent that reinforcers were delayed temporally from key pecks, a result consistent with the present data. An account of changing from conjoint VI VI to concurrent VI VT in terms of relative reinforcement frequency changes, favored by Rachlin and Baum, could predict either a decrease or no change in responding. If the VT reinforcers were contiguous with key pecks, they might function as response-dependent reinforcers. This would lead to no change in response rates because all of the reinforcers, metaphorically, would be attributed to key pecking and therefore would render the condition identical to the conjoint VI VI. If, alternatively, the two sources of

reinforcement (Lattal, 1975, 1979, 1981), the presence or absence of dependency in the sources of reinforcement would be distinct and key pecking would be expected to decrease. Such a molar interpretation assumes both a reinforcing and a discriminative function of the response-reinforcer relation (Lattal, 1981).

Both logical and empirical arguments have been made against the notion of superstitious conditioning based on adventitious reinforcement and its emphasis on molecular response-reinforcer temporal contiguity as central to the reinforcement effect (e.g., Baum, 1973; Rescorla & Skucy, 1969; Staddon & Simmelhag, 1971; Timberlake & Lucas, 1985). Williams (1983) offered the example of Fenner's (1980) failure to replicate Staddon and Simmelhag (1971) as one cautionary note against the premature rejection of the contiguity principle in explanations of behavior. The present results offer another. Although the contiguity principle may be shown empirically to be invalid, the case must be built carefully. The present results suggest that an account of the effects of concurrently available response-independent food delivery on operant behavior in terms of the temporal relations between responses and food delivery is not precluded.

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