EFFECTS OF REINFORCEMENT MAGNITUDE ON PIGEONS' PREFERENCE FOR DIFFERENT FIXED-RATIO SCHEDULES OF REINFORCEMENT¹

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In concurrent, two-member chains, the completion of one or the other of two initial percentage fixed-interval 90-sec links produced a terminal link in which the completion of a fixed ratio produced food reinforcement. The fixed ratios and the duration of reinforcement in the terminal links were varied. Relative response rate in initial links was proportional to the relative reinforcement duration per ratio response (reinforcement duration divided by fixed ratio) in terminal links. The rate of responding in the terminal fixed-ratio links was insensitive to both ratio size and reinforcement duration and therefore did not vary sufficiently to distinguish between responses per reinforcement and immediacy of reinforcement as controlling variables in terminal links.

Reinforcement magnitude, manipulated by controlling the duration of access to food, had little effect on single-key variable-interval (VI) responding, but responding maintained by concurrent VI VI schedules (two schedules operating simultaneously and independently for different responses) was directly proportional to reinforcement magnitude (Catania, 1963). In Shettleworth and Nevin's (1965) study with multiple schedules, in which two component schedules were alternated regularly, each in the presence of a different stimulus, relative response rate varied as a linear function of relative reinforcement magnitude.

In both Catania's (1963) and Shettleworth and Nevin's (1965) experiments, VI schedules were employed; thus, the number of responses per reinforcement could vary. These experiments did not provide data relating reinforcement magnitude and the number of responses required per reinforcement. The present ex-

periment examined this relationship using concurrent chained schedules, in which reinforcement depends on the successive completion of two or more component schedules, each of which operates in the presence of a different stimulus (Autor, 1960; Herrnstein, 1964). Relative responding in the initial, concurrent percentage fixed-interval (FI) links (schedules in which a fixed proportion of the reinforcements are omitted) of two link chains was taken as a measure of preference for one of two combinations of response requirement (fixed ratio) and reinforcement duration in the terminal chain links. The study attempted to determine how preference for different reinforcement durations depended on the number of responses required to produce reinforcement.

METHOD

Subjects

Three adult male White Carneaux pigeons (46, 66, and 71) had varied experimental histories; the fourth (253) was experimentally naive. The pigeons were maintained at about 80% of their free-feeding weights.

Apparatus

The panel of a standard pigeon chamber, insulated from outside visual and auditory stimuli, was modified to contain three translucent response keys, 8 in. from the floor of the chamber and 4 in. apart, center to center. The keys could be illuminated from behind

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with either green light, or three black vertical lines on a white background, and were operated by a minimum force of about 15 g. A standard feeder was situated below the center key. A white light (housetlight), located in the upper right corner of the panel, was lit except during reinforcement, when a white light inside the feeder was lit. Relay circuitry, electromechanical counters, and cumulative recorders were used for scheduling and data recording.

Procedure

Training procedure. Pigeon 253, naive at the start of the experiment, was trained to eat from the magazine, trained to peck a key, and brought under the control of a fixed ratio (FR) 50 within two, 1-hr sessions. At this point, all four pigeons were subjected to identical procedures for the remainder of the experiment. An FR 100 schedule was arranged on the center key until the pigeons were completing the ratios without any signs of strain (pauses after responding had begun). Then the FR was reduced to 10, and an FI 10-sec schedule, the completion of which turned on a matching center-key stimulus, was introduced on each of the side keys. Although the side keys were lit simultaneously, the onset of the center-key stimulus was scheduled for only one key in each sequence. Thus, the pigeons were forced to switch between keys. Once switching behavior was established, the values of the FI and FR schedules were gradually increased until they matched the upper limits of the experimental procedure. These values were maintained for 36 sessions, each session consisting of 50 reinforcements. The stimuli employed during training were different from those employed during the experiment.

Experimental procedure. After each reinforcement, concurrent percentage FI 90-sec FI 90-sec schedules of reinforcement operated on the side keys, with vertical lines on the left key, and green on the right. The center key was dark. After 90 sec, a response on one of the side keys turned on the matching stimulus on the center key and turned off the stimuli on the side keys. The completion of an FR on the center key then produced food reinforcement, after which the cycle restarted (Fig. 1).

To insure that responding continued on both side keys, center-key onset was scheduled for only one of the two side keys during each

initial link. For example, if the FI was scheduled for the green key in a given cycle, then responses on the vertical side key had no consequences in that cycle; a response on the green side key after 90 sec turned the center key green. The probabilities of the two FI schedules were each 0.50, thus insuring equal exposure to the two terminal chain links, and their order of presentation was such that the relative frequencies of the four possible two-cycle sequences were 0.25. This arrangement impaired the independence of the FIs, suggesting that they were not true concurrent schedules, but rather a single FI on a two-key operandum. However, they could also be considered as concurrent percentage reinforcement schedules, in which, for each FI schedule, reinforcement was omitted in half the intervals, when it was arranged for the other schedule. Each pigeon was run daily, and each session was terminated after 50 cycles or 100 min, whichever occurred first.

In the terminal links of the chains, which operated separately rather than concurrently, different combinations of fixed ratios and reinforcement durations were correlated with each of the stimuli (Table 1). The ratios ranged in value from 10 to 75, and the reinforcement durations from 1.0 to 7.5 sec. The resulting

Fig. 1. Diagram of one cycle of the experimental procedure. At the start of a cycle the two side keys were lit and the center key was dark. After 90 sec (FI 90-sec), a response on the appropriate side key turned on the matching stimulus on the center key, and darkened the side keys. The completion of a fixed ratio (FR) on the center key then produced food reinforcement, after which the cycle restarted.

Table 1
Summary of Procedures and Absolute Fixed-Interval Response Rates for Each Pigeon

Conditions Scheduled in Terminal Chain Link					Absolute FI Response Rates in Initial Chain Links (response/min)												
Vertical FR	Green RFT (Sec)	FR	Green RFT (Sec)	Relative Rein- forcement (sec) per Response	Sessions	46			66			71			253		
						Vertical	Green	Vertical	Green	Vertical	Green	Vertical	Green	Vertical	Green	Vertical	Green
50	5.0	10	5.0	0.17	21	2.6	26.1	8.6	44.2	6.3	29.9	9.6	26.9	15.5	23.8	13.0	15.7
50	5.0	10	1.0	0.50	24	6.2	11.1	22.9	21.0	22.7	13.1	15.5	23.8	13.0	15.7	13.0	15.7
50	7.5	50	5.0	0.60	20	7.5	5.7	20.5	18.6	16.8	12.7	16.4	8.8	16.4	8.8	16.4	8.8
25	5.0	25	5.0	0.50	18	10.2	9.6	19.1	29.5	16.1	13.0	17.5	15.3	17.5	15.3	17.5	15.3
50	5.0	25	2.5	0.50	21	8.3	8.1	15.5	21.2	14.4	10.9	13.6	14.4	14.4	14.4	13.6	14.4
50	5.0	75	5.0	0.60	20	10.6	1.2	15.2	28.5	15.6	10.1	19.3	8.3	19.3	8.3	19.3	8.3
50	5.0	50	1.0	0.83	24	14.9	0.7	31.0	7.9	21.7	6.8	30.0	5.9	30.0	5.9	30.0	5.9
50	1.0	50	5.0	0.17	23	4.9	20.2	7.9	31.6	13.7	19.4	13.9	13.2	13.9	13.2	13.9	13.2
10	2.5	10	5.0	0.33	23	3.4	9.5	14.1	25.9	16.8	22.5	17.4	19.9	17.4	19.9	17.4	19.9
25	5.0	50	5.0	0.67	21	12.6	1.1	27.7	18.2	17.7	10.9	18.5	15.4	18.5	15.4	18.5	15.4
50	5.0	50	7.5	0.40	18	5.0	11.7	14.1	26.6	8.0	11.9	12.8	14.9	12.8	14.9	12.8	14.9
10	5.0	50	5.0	0.83	18	21.8	0.7	38.9	14.7	21.5	10.4	26.6	9.5	26.6	9.5	26.6	9.5
20	5.0	10	5.0	0.33	24	3.2	13.7	19.3	32.8	11.3	19.4	14.9	23.3	14.9	23.3	14.9	23.3
50	5.0	50	2.5	0.67	18	20.9	1.3	25.0	12.6	15.4	8.9	19.2	7.2	19.2	7.2	19.2	7.2
75	5.0	50	5.0	0.40	18	3.3	9.7	16.6	21.0	9.4	14.1	13.0	15.7	13.0	15.7	13.0	15.7

relative reinforcement durations per ratio response were determined by the formula:

$$\frac{\text{Key A Reinf. Duration}}{\text{Key A Fixed Ratio}} + \frac{\text{Key B Reinf. Duration}}{\text{Key B Fixed Ratio}}$$

where Key A is the left key, with the vertical-line stimulus, and Key B is the right key, with the green stimulus.

Values of this variable of 0.17, 0.33, 0.40, 0.50, 0.60, 0.67, and 0.83 were arranged in an irregular order. Each value, except 0.50, was arranged in two ways: once with reinforcement durations equal, and once with fixed ratios equal. The value of 0.50 was arranged in three ways: twice with neither reinforcement durations nor fixed ratios equal, and once with both equal (*cf* Table 1).

For each pigeon, data were taken across the last five sessions of each procedure. Reinforcement magnitude was assumed to vary with reinforcement durations. The evidence to support this assumption was that the weight gained per session varied consistently with total reinforcement duration per session.

RESULTS

Figure 2 shows relative FI responding as a function of relative reinforcement duration

Fig. 2. Relative FI response rate [vertical FI rate/(vertical FI rate + green FI rate)] as a function of relative reinforcement time per ratio response [vertical reinforcement time per vertical ratio response/(vertical reinforcement time per vertical ratio response + green reinforcement time per green ratio response)].

per ratio response, for each pigeon. The dashed lines represent matching, *i.e.*, a direct proportionality between dependent and independent variables. In the case of Pigeons 66 and 71, only three of the 15 points deviate from the matching function by more than 0.05. Four of the points for Pigeon 253 and seven of the points for Pigeon 46 deviate from the matching function by more than 0.05. There are no systematic differences between the points obtained when both ratios (filled triangles) and reinforcement durations (open circles) were held equal. The values plotted at 0.50 on the abscissa illustrate these relationships. Only one point (for Pigeon 71) deviates from the matching line by more than 0.05, and there is no systematic relationship between open triangles and filled circles. The triangle falls between the circles once, above them once, and below them twice.

Figure 3 shows relative FI response rate as separate functions of relative reinforcement time and the reciprocal of relative FR. (The reciprocal makes relative measures decrease with increasing FR, so that increases in reinforcement duration and decreases in FR have effects in the same direction.) Neither relative reinforcement duration nor relative ratio alone yields a systematic relationship to relative FI response rate (open circles in the left half of Fig. 3, and filled triangles in the right half). The only points which follow the matching function are those obtained when either FR requirement (filled triangles, on the left), reinforcement duration (open circles, on the right), or both (open triangles) are held equal,

Fig. 3. Relative FI response rate [vertical FI rate/(vertical FI rate + green FI rate)] as a function of relative reinforcement time [vertical reinforcement time/(vertical reinforcement time + green reinforcement time)] and of the reciprocal of relative FR [vertical 1/FR/(vertical 1/FR + green 1/FR)]. Dashed lines represent a matching relationship. Data are averaged across subjects.

in which case the relative reinforcement durations and relative ratios in Fig. 3 are equal to the relative reinforcement duration per ratio response in Fig. 2.

Intra-subject variability in overall FI response rate for different sets of FR and reinforcement-duration values is shown in Table 1, which presents mean absolute response rates (responses per minute) in each FI for each pigeon across the last five sessions of each procedure. There is no apparent systematic relationship between FI rate and either total reinforcement duration or total FR requirement. Within each set of terminal-link values, there was little session-to-session variability in overall FI response rates. Standard deviations in FI rate were computed for each of the pigeons for the last five sessions of each procedure. Only 10 of the 60 deviations obtained represented more than 5% of the mean response rate. Of these 10, seven were for Pigeon 46, whose data were in general the most variable and the most deviant from the data of the other pigeons and the group.

There was also little session-to-session variability in relative FI response rate within each set of FR and reinforcement-duration values. Relative FI rates for the last five sessions of each procedure were compared with the mean for those sessions for each pigeon, thus totaling 300 comparisons. Of these, there were only 28 cases of variations in relative rate greater than 0.05.

Table 2 presents the mean absolute response rates (responses per minute) of each pigeon in the terminal chain-link FRs, across the last five sessions of each procedure. For each procedure, there are few within-subject variations in rate, either as a function of ratio size, or of reinforcement duration. This lack of variation suggests that the terminal-link FR and reinforcement-duration values, which affected FI performance in the initial links, did not affect the FR performance itself. This is consistent with the finding that simple schedules of reinforcement, like the FR component of the chain described here, are not sensitive to variations in the magnitude of reinforcement, while concurrent schedules may be (e.g., Catania, 1963). The FR performance typically consisted of brief pauses at the onset of the center-key stimulus, followed by rapid and uninterrupted responding until the ratio was completed. On the other hand, the FI performance typically consisted of very few responses early in the interval, gradually increasing to a high terminal response rate. Changeover responses in the FI occurred almost exclusively toward the end of the interval, particularly at extreme values of the relative reinforcement duration per ratio response. No quantitative measures were obtained of either FR pauses or FI curvature.

In the instances in Table 2 where response rates for the two ratio values within each procedure differed by more than 3%, relative time

Table 2
Absolute Fixed-Ratio Response Rates for Each Pigeon

Conditions Scheduled in Terminal Chain Link				Absolute FR Response Rates in Terminal Chain Links (response/min)							
Vertical		Green		46		66		71		253	
FR	RFT (sec)	FR	RFT (sec)	Vertical	Green	Vertical	Green	Vertical	Green	Vertical	Green
50	5.0	10	5.0	149	92	217	214	166	152	324	294
50	5.0	10	1.0	107	112	222	229	166	135	316	301
50	7.5	50	5.0	109	88	208	208	190	171	272	260
25	5.0	25	5.0	133	126	144	153	159	161	330	318
50	5.0	25	2.5	126	115	215	197	157	159	347	341
50	5.0	75	5.0	117	118	198	202	160	165	416	400
50	5.0	50	1.0	117	117	153	156	162	136	442	440
50	1.0	50	5.0	110	118	178	180	127	133	406	404
10	2.5	10	5.0	96	95	163	165	114	119	246	249
25	5.0	50	5.0	106	112	191	191	167	169	376	380
50	5.0	50	7.5	128	129	203	210	170	174	409	394
10	5.0	50	5.0	92	96	212	206	135	174	234	374
20	5.0	10	5.0	133	122	178	164	161	145	312	278
50	5.0	50	2.5	117	108	152	158	161	160	327	331
75	5.0	50	5.0	100	110	168	174	152	152	332	342

to completion of the FRs was substituted for relative FR requirement in the formula above, and the relative functions in Fig. 2 were re-examined. This change, suggested by Chung and Herrnstein's (1967) analysis of choice as a function of immediacy of reinforcement (reciprocal of delay), did not affect the points in Fig. 2 in any systematic way. Regression lines (in the form $y = mx + b$, where m is the slope, b is the y -intercept, y is relative FI response rate, and x is either relative reinforcement duration per response or relative reinforcement duration per second in the FR) were computed for individual pigeons and for the group (Table 3). It was impossible to distinguish between the two variables on the basis of adequacy of matching, which would yield functions in which $m = 1$ and $b = 0$.

DISCUSSION

The obtained relationship between relative FI response rate and relative reinforcement duration per ratio response suggests that an increase in reinforcement duration can systematically compensate for an increased ratio requirement. For example, one can make up for doubling the size of an FR by doubling the magnitude of reinforcement. Also, Fig. 3 shows that neither relative FR requirement nor relative reinforcement magnitude has a systematic effect on FI responding if both variables are not taken into account. However, since the relative reinforcement duration per ratio response did not influence the terminal, simple FR responding, but rather the concurrent initial FI responding, the generality of the phenomenon may be limited to this specific procedure. Procedural details appear to influence data on reinforcement magnitude generally. For example, as is well documented, matching occurs in concurrent but not in multiple schedules. Shettleworth and Nevin (1965) did not obtain a matching relationship between reinforcement magnitude and response rate in a multiple schedule; the present experiment, like Catania's (1963), yielded a function which closely approximated matching. In addition, terminal-link performance in chained schedules has been shown to be rather insensitive to a number of variables, including both reinforcement frequency (Findley, 1962) and reinforcement magnitude (Neuringer, 1967).

The present procedure differed from past studies of preference with chained schedules in that the initial links consisted of fixed intervals rather than variable intervals. This procedure appeared to minimize session-to-session variability in both absolute and relative response rates. Only 17% of the standard deviations in absolute FI response rates for the last five sessions at each set of FR and reinforcement-duration values represented more than 5% of the mean absolute FI response rates. Similarly, only 10% of the relative FI response rates for those sessions differed from their means by more than 5%. In addition, the similarity between the results obtained in the present study and past studies (*e.g.*, Herrnstein, 1964) suggests that data obtained with variable intervals as initial chain links may be generalized to fixed-interval procedures.

The present data may be accounted for either in terms of rate of reinforcement (reinforcement duration per time to completion of the FR) or by probability of reinforcement (reinforcement duration per ratio response). Chung and Herrnstein (1967) pointed out that there is a matching relationship between rate of responding and delay of reinforcement, a temporal variable. In addition, they suggested that the matching relationship obtained by Catania (1963) with reinforcement magnitude as the independent variable may also be considered a function of temporal variables, since reinforcement magnitude in that study (as in the present one) was manipulated by varying reinforcement duration. Herrnstein (1964) also found the temporal variable to be the critical one in an attempt to separate the effects of probability of reinforcement (reinforcements per response) and rate of reinforcement (reinforcements per unit time) on response rate. The rate of reinforcement function was closer to matching, and accounted for more variability, than the probability of reinforcement function.

However, there are data which suggest that modifications of the matching function which characterizes the relationship between response rate and variables like delay, magnitude, and frequency of reinforcement are necessary. Relative values of 0.0 and 1.0 of these variables are identical with (for frequency) or analogous to (for delay and magnitude) concurrent VI-extinction schedules. Catania (1966, p. 217) found that with concurrent

VI-extinction schedules, responding on the extinction key could not be eliminated as long as responses on the other key were being reinforced, and there was no changeover delay. This low rate of responding in extinction probably persisted because of some delayed reinforcement of responses on the extinction key which closely preceded responses on the VI key. Changeover delays were not employed in the present study, thus making delayed reinforcement effects more likely. Thus, one would predict that when the relative value of the independent variable was 0.0, relative response rate would be greater than 0.0, and that when the relative value of the independent variable was 1.0, relative response rate would be less than 1.0, because of the persistence of responding in extinction. The empirical matching function would then have to be modified so that its slope was less than 1.0 and its y-intercept was positive. It is interesting to note that Herrnstein's (1964) mean regression line for probability of reinforcement better satisfies these modifications than the mean regression line for rate of reinforcement. In addition, although the data from the present experiment almost uniformly satisfy these modifications (Table 3), the relationship between the

respect to FI responses was substantially delayed.

None of the data presented above permit differential evaluation of temporal and response variables for the present experiment. Although FR requirements had an effect on preference, FR rates were relatively constant (Table 2), and thus FR time varied directly with FR size. However, these two variables may be separated within the general methodological framework of the present experiment. If time is the critical variable, then substituting relative delays of reinforcement for relative response requirements should alter the obtained function little. On the other hand, if responses are the critical variable, then varying FR requirement while keeping FR time constant should have little effect on the obtained function. Either of these procedures may permit further exploration of the phenomena obtained in the present experiment.

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Table 3

Equations of regression lines for relative fixed-interval response rate as separate functions of relative reinforcement duration per ratio response, and relative reinforcement duration per time to completion of the fixed ratio.

Pigeon	Duration per Response	Duration per Sec
(x = relative reinforcement)		
46	$y = 1.52x - 0.23$	$y = 1.30x - 0.15$
66	$y = 0.85x + 0.03$	$y = 0.75x + 0.10$
71	$y = 0.68x + 0.19$	$y = 0.60x + 0.23$
253	$y = 0.78x + 0.13$	$y = 0.85x + 0.07$
Group	$y = 0.93x + 0.04$	$y = 0.94x + 0.04$

Catania experiment and the present one may be limited. In the Catania experiment, primary reinforcement was immediate; in the present study, primary reinforcement with