FIXED-RATIO DISCRIMINATION: EFFECTS OF INTERMITTENT REINFORCEMENT

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Four pigeons had discrimination training that required the choice of a left side-key after completing a fixed-ratio 10 on the center key, and a right side-key choice after fixed-ratio 20. Correct choices were reinforced on various fixed-interval, fixed-ratio, random-interval, and random-ratio schedules. When performance was examined across successive 15-second intervals (fixed-interval and fixed-ratio schedules) accuracy was high in the first 15-second interval, decreased in one or several of the next 15-second intervals, and then increased again as reinforcement was approached. When performance was examined across correct trials on fixed-interval and fixed-ratio schedules, accuracy was lowest immediately after reinforcement, followed by a systematic increase in accuracy as the number of correct choices increased. These patterns were due primarily to errors on fixed-ratio 20 trials. Systematic accuracy patterns did not occur on random-interval or random-ratio schedules. The results indicate that when choice patterns differed on fixed-interval and fixed-ratio schedules, the differences were due to the method of data analysis.

Key words: fixed-ratio discrimination, conditional discrimination, intermittent reinforcement, choice patterns, key peck, pigeons

Schedules of reinforcement specify the relationship between behavior and reinforcement. Although the performance of organisms under reinforcement schedules has been extensively studied with simple responses, relatively little research has been done with more complex performances. Of the work with complex performances, much has been with conditional discrimination tasks. One of the more notable effects of intermittent reinforcement of conditional discrimination performance is that specific patterns of choice accuracy occur between reinforcements, with these patterns appearing to be a function of the prevailing schedule of reinforcement.

On fixed-interval (FI) schedules, where reinforcement depends on a correct choice occurring after the end of a specific time interval, accuracy is frequently lower during the second quarter of intervals than during the

first, third, or fourth quarters (Boren and Gollub, 1972; Clark and Sherman, 1970; Davidson and Osborne, 1974; Ferster, 1960). On fixed-ratio (FR) schedules, where reinforcement depends on a specific number of correct choices, accuracy is lowest at the beginning of the ratio, followed by a systematic increase in accuracy as the ratio count advances (Davidson and Osborne, 1974; Mintz, Mourer, and Weinberg, 1966; Nevin, Cumming, and Berryman, 1963; Stubbs, 1968). Such accuracy patterns have not been found when reinforcement is made available randomly in time or randomly across correct choices (*e.g.*, Davidson and Osborne, 1974; Nevin *et al.*, 1963).

The data on intermittent reinforcement of conditional discrimination performance suggest that FI and FR schedules control different patterns of choice accuracy. However, an adequate demonstration of schedule-specific choice patterns has not been made. Specifically, FI patterns have been determined according to accuracy across time, while FR patterns have been determined across correct trials. Thus, because different types of data analyses have been involved, the resulting choice patterns on FI and FR reinforcement could not be compared directly. An explicit

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comparison of FI and FR choice would require that the same analysis be applied to performances on both schedules.

The present study examined conditional discrimination choice patterns where performances on FI and FR schedules were examined both across correct trials as well as across time. The experiment used an FR discrimination task in which the choice of two side keys was based on whether a short or a long FR had just been completed on the center key (*e.g.*, Pliskoff and Goldiamond, 1966; Rilling and McDiarmid, 1965).

METHOD

Subjects

Four male White King pigeons maintained at $75\% \pm 15$ g of their free-feeding weights, served. All birds had prior training on FR discrimination (Lydersen and Crossman, 1974).

Apparatus

The laboratory-constructed experimental chamber was 45.7 cm long, 61.0 cm wide, and 53.3 cm high, and contained three response keys and a grain hopper. The keys were 2.5 cm in diameter, 6.4 cm apart, center-to-center, 24.1 cm above the floor, and required a minimum force of about 0.15 N for operation. Every response to a transilluminated center key produced an audible click from a relay located behind the key; side-key responses produced no explicit auditory feedback. Purina Racing Pigeon Checkers were occasionally made available for 5 sec through a 6.4-cm wide and 5.1-cm high aperture centered below the response keys. White light illuminated the aperture during reinforcement. A sound-attenuating housing, white noise, and a ventilating fan served to mask most extraneous stimuli. Automatic control and recording equipment were located in an adjacent room.

Procedure

Because of prior experience with the task, no pretraining was required. A trial started with the presentation of a white center key. After completion of either FR 10 or FR 20, the center key was darkened and the two side keys were transilluminated with green on the left and red on the right. If FR 10 was in ef-

fect, a right-side response produced reinforcement and a left-side response produced a 5-sec blackout, during which the chamber was dark. If FR 20 was in effect, a left-side response produced reinforcement and a right-side response produced the blackout. The next trial followed immediately after reinforcement or blackout. The two FRs were scheduled equally often in a mixed, repeating block of 42 trials, restricted so that no more than three identical FRs could occur in succession. Sessions terminated after 51 reinforcements. This procedure continued until stable accuracy was obtained. Correct choices were then reinforced according to the schedules listed in Table 1. Also shown are the order of training and the number of sessions on each schedule.

Fixed-ratio schedules specified the number of correct choices required to produce reinforcement. Nonreinforced correct and incorrect choices on FR, and all other schedules, produced a 5-sec blackout and then the next trial. On random-ratio (RR) schedules, correct choices operated a probability generator that determined if the choice would produce reinforcement. The RR values indicate the mean number of correct choices required. On FI schedules, the first correct choice that occurred after the specified interval of time had lapsed produced reinforcement. Finally, on random-interval (RI) schedules, a continuous series of timed pulses operated a probability generator. An output by the probability generator made reinforcement available for the next correct choice. The RI values indicate the mean time between reinforcement availability.

The first correct choice at the start of sessions always produced reinforcement. Subsequent reinforcements were obtained according to the prevailing schedule. Sessions were terminated after 31 reinforcements (FR 16, RR 16, FI 4-min, and RI 4-min schedules), 51 reinforcements (all other schedules), or 4 hr, whichever occurred first. With few exceptions, sessions were conducted daily. Each schedule remained in effect until stable accuracy was obtained. Stability was assumed when the mean accuracy on each of two consecutive blocks of five sessions was within 1% of the 10-session mean. In addition, on FI and FR schedules, the stability criterion was not applied until visual inspection of

Table 1

Per cent correct choices for each bird across the last 10 sessions of each schedule. The first number in parentheses shows the order of training on schedules and the second number indicates the number of sessions of training.

<i>Schedule</i>	<i>Bird C1</i>	<i>Bird C2</i>	<i>Bird C3</i>	<i>Bird C4</i>
FR 1	93% (1-38)	92% (1-44)	91% (1-31)	92% (1-41)
FR 4	82% (2-36)	81% (8-30)		85% (5-36)
FR 8	82% (3-29)	86% (9-20)		81% (6-50)
FR 16	80% (4-28)	84% (10-25)		76% (7-39)
RR 4	92% (5-16)		94% (8-18)	89% (2-22)
RR 8	94% (6-14)		95% (9-12)	88% (3-21)
RR 16	95% (7-12)		96% (10-11)	91% (4-15)
FI 1-min	85% (8-33)	87% (2-35)	81% (5-44)	
FI 2-min	86% (9-34)	84% (3-35)	84% (6-28)	
	83% (11-37) ^a			
FI 4-min	88% (10-47)	84% (4-45)	90% (7-38)	
RI 1-min		91% (5-26)	92% (2-22)	91% (8-18)
RI 2-min		94% (6-16)	94% (3-16)	93% (9-17)
RI 4-min		93% (7-11)	95% (4-12)	92% (10-12)

^aReplication

daily choice patterns revealed no systematic changes.

RESULTS

Table 1 shows the mean per cent correct choices across the last 10 sessions on each schedule for each bird. Two general effects on accuracy by the schedules of reinforcement can be seen. First, both FI and FR 4 to 16 reinforcement produced lower accuracy than that obtained on FR 1. Second, both RI and RR reinforcement produced accuracy at, or slightly higher than, that controlled by FR 1.

The effects of different values of any one type of schedule are less clear. Accuracy on FR reinforcement decreased as the ratio increased for two birds (C1 and C4), while the third bird (C2) had the lowest accuracy on FR 4. The effect of increasing the FI value was in the opposite direction. The accuracy for Birds C1 and C3 increased with increases in FI value, while Bird C2 had the highest accuracy on FI 1-min.

Figure 1 shows selected portions of cumulative response records for Birds C1 and C2. The FI and FR records were quite similar. Typically, reinforcement was followed by a pause in responding. The first several choices after the pause usually were correct if the stimulus ratio was FR 10. However, if the stimulus ratio was FR 20, the first several choices frequently were errors. Responding on the first several trials was associated with

occasional within-ratio pausing that rarely occurred on later trials. Beyond the first several trials, errors were relatively infrequent, but with most errors still occurring on FR 20 trials. On RI and RR schedules, trials were completed with relatively few pauses. Trials that did follow pauses were about as accurate as other trials. The performance by Birds C3 and C4 showed a similar relationship between schedule type and cumulative response records as those presented in Figure 1.

Figure 2 shows the choice accuracy on FI reinforcement within successive 15-sec intervals. Correct choices occurring in or after interval 5 (FI 1-min), 9 (FI 2-min), or 17 (FI 4-min) produced reinforcement. The functions for each condition were continued until three successive intervals contained fewer than 10 trials; the performance on these three intervals and any later trials is represented by unconnected data points on each panel. For each schedule, accuracy on all trials that terminated in the first 15-sec interval was higher than the accuracy within one or more of the immediately following 15-sec intervals. Accuracy then increased as the end of the interreinforcement interval approached. Accuracy on trials completed after reinforcement was set up was lower than just before reinforcement was available. These late choices often followed long postreinforcement pauses or, less frequently, long within-schedule pauses. Figure 2 also shows the accuracy within 15-sec intervals separately for

Fig. 1. Selected cumulative response records of FR 10 and FR 20 performances for Birds C1 and C2 from the last session on each schedule. Correct choices are indicated by a diagonal slash of the response pen. When a correct choice was reinforced, the pen remained down during the reinforcement time. Errors are indicated by a dot above and to the left of a pause in responding. The recorder operated continuously during sessions.

FR 10 and FR 20 trials. Generally, the accuracy on FR 10 trials was high and relatively stable across successive intervals. The highest percentage of errors was on FR 20 trials.

Figure 3 shows the choice accuracy across successive correct trials. That is, the first ordinal position in each panel includes all choices up to and including the first correct choice; the second ordinal position includes all trials after the first correct choice to the second correct choice; *etc.* The overall accuracy was lowest at the beginning of FR schedules, followed by a systematic increase in accuracy as the subjects progressed through the ratios. When the FR 10 and FR 20 trials were examined separately, errors predominated on FR 20 trials, with the notable exception of Bird C1 on FR 4.

In Figure 4, the accuracy on FI schedules was determined across successive correct choices, exactly as was done in Figure 3 for FR performances. The overall accuracy on FI reinforcement increased as the number of

correct choices increased within interreinforcement intervals. Further, the majority of errors occurred on FR 20 trials. Thus, both FI and FR reinforcement produced similar accuracy patterns when examined across trials.

In Figure 5, the accuracy on FR reinforcement was determined within successive 15-sec intervals, as was done for FI performances in Figure 2. For all birds, the accuracy on trials that terminated in the first 15-sec interval was higher than in one or more of the immediately following 15-sec intervals. This initial decrease in accuracy was then followed by a gradual increase in accuracy across subsequent intervals. The irregular accuracy that occurred after a period of high and relatively stable choice accuracy was usually due to choices that followed either long postreinforcement pauses or to occasional within-ratio pausing.

Table 2 shows the median number of correct choices and the median interreinforcement intervals on FI and FR schedules. The

Fig. 2. Choice accuracy across successive 15-sec intervals on FI schedules for each bird. See text for additional details.

median number of correct choices on FI 1-min was identical to, or within one trial, of that required on FR 4. The median time between reinforcements also was similar on FI 1-min and FR 4 schedules. Other pairs of FI and FR schedules were less comparable.

Figure 6 shows the number of FR 10 and FR 20 trials completed across successive 15-sec intervals and across successive correct choices both on FI and FR schedules for Bird C1. On FI schedules, the number of trials in each 15-sec interval increased systematically up to the interval that preceded reinforce-

ment availability, followed by a rapid decrease in trials. The number of trials across successive 15-sec intervals on FR schedules was similar, except that the subsequent decline in the number of trials was more gradual than on FI reinforcement. On both FI and FR schedules, the number of trials per successive correct choice was usually highest immediately after reinforcement, with a decreasing number of trials as the number of correct choices increased. The remaining birds had very similar performances to those shown for Bird C1.

Table 2

The median number of correct choices and the median interreinforcement intervals across the last 10 sessions on FR and FI schedules for each bird. Time measurements are in multiples of 6 sec.

<i>Schedule</i>	<i>Subject</i>	<i>Median Number of Correct Choices</i>	<i>Median Interreinforce- ment Intervals (sec)</i>
FR 4	C1	4	66
	C2	4	96
	C4	4	78
FR 8	C1	8	192
	C2	8	210
	C4	8	192
FR 16	C1	16	312
	C2	16	462
	C4	16	876
FI 1	C1	4	66
	C2	4	60
	C3	3	66
FI 2	C1	7	126
	C2	7	126
	C3	5	126
FI 4	C1	11	240
	C2	12	246
	C3	11	240

Typically, the first 15-sec interval on FI and FR schedules contained more FR 10 than FR 20 trials, as did the trials up to, and including, the first correct choice. Although this appears to contradict the fact that trials were in a randomized sequence, the effects were actually due to the shorter time taken to complete FR 10 trials and to the preference for one of the two side keys. For example, assume that FR 10 trials required about 3 sec between the first and last response and FR 20 required about 6 sec (these times are for illustrative purposes and were not measured). Any trial initiated between 9 and 12 sec through the first 15-sec interval would be completed during the first interval if it was an FR 10, but would be completed in the second 15-sec interval if the trial was FR 20. Thus, other things equal, more FR 10 trials than FR 20 trials could be completed during the first 15-sec interval.

The larger number of the preferred type of trial in the first bin of the across successive correct choices functions can be explained by the following example. Consider a hypothetical case where early FR 10 trials always resulted in correct choices and early FR 20

trials were never correct. This would result in the first bin per interreinforcement interval always containing an FR 10 trial, but need not contain an FR 20 trial. Because of the bias for choosing the correct side key on FR 10 trials, more FR 10 trials would occur in the first bin. To lesser degrees than the above example, this was the case for all but one condition. For Bird C1 on FR 4, the reverse was true; the correct side key on FR 20 was preferred and there were more FR 20 than FR 10 trials in the first bin.

DISCUSSION

The present results extend the known effects of intermittent reinforcement of conditional discrimination performance to an FR discrimination task. On FI reinforcement, choice accuracy was higher during the first 15 sec and the last half of interreinforcement intervals than at other times. Further, FR reinforcement resulted in a systematic increase in choice accuracy as the ratio count advanced. Finally, on RI and RR schedules, choice accuracy was constant between reinforcements. Thus, the interreinforcement accuracy patterns were the same as those previously obtained with matching-to-sample and temporal discriminations (*e.g.*, Ferster, 1960; Nevin *et al.*, 1963; Stubbs, 1968).

Although the choice patterns differed on FI and FR reinforcement when performances were analyzed in the same way as has been done in prior studies, the results suggest that these differences were largely a function of the specific methods of data analysis. This was shown by an examination of performances both across time and across correct trials on FI and FR schedules. When choice on FI schedules was determined across successive correct choices, accuracy increased as a direct function of the number of correct choices. This is the same accuracy pattern as that obtained on FR schedules examined across successive correct choices. Similarly, when performance on FR schedules was determined across successive 15-sec intervals, the lowest accuracy occurred after the first 15-sec interval, as did FI performances determined in the same way. Thus, the present results indicate that FI and FR schedule-produced choice patterns were analysis-specific, rather than schedule-specific.

Fig. 3. Choice accuracy across successive correct trials on FR schedules for each bird. See text for additional details.

As Boren and Gollub (1972) noted, comparisons of FI and FR performances are frequently made difficult because, in existing conditional discrimination studies, the two differed considerably on either the number of correct trials or the time between reinforcements. However, the present procedures permitted comparisons of performances on FI and FR schedules where both the interreinforcement intervals and the number of correct choices were nearly equal. Comparisons between FI 1-min and FR 4 schedules were especially appropriate, because the number of correct trials were identical for all but

one of the conditions (Bird C3 on FI 1-min), and the median interreinforcement intervals were also quite similar. It seems reasonable to conclude that the accuracy patterns obtained on the schedules examined were not due to differences across schedules in either the number of correct choices or the median interreinforcement intervals.

A further result was that the FI and FR schedules affected accuracy primarily on only one of the two types of trials. For most conditions, errors predominated on FR 20 trials, with these errors occurring primarily early during ratios and intervals. Thus, errors were

Fig. 4. Choice accuracy across successive correct trials on FI schedules for each bird.

associated both with the ratio that required the longest time to complete and with the choice preference of one of the two side keys.

This selective effect suggests a partial explanation of the error patterns obtained within interreinforcement intervals. Because the postreinforcement pause often exceeded the first several 15-sec intervals, relatively few trials terminated here. However, of the trials that did terminate early, a majority were FR 10 trials and were also correct. Thus, the per cent correct choices early during interreinforcement intervals was biased because that time contained a majority of trials that required the least time to complete and on which the preferred side key was correct. In subsequent 15-sec intervals, the accuracy decreased because the first FR 20 trials in each

interreinforcement interval commonly terminated here and were frequently incorrect. The higher accuracy in subsequent 15-sec intervals was due to the increasing accuracy on FR 20 trials.

Although this analysis may be specific to only FR discrimination performances, it might be applicable to the accuracy patterns on matching-to-sample as well. That is, the time between the start of matching trials and a choice response would have to be consistently shorter in the presence of one of the sample stimuli than in the presence of other samples; this sample would also have to control higher accuracy than other samples. Such differential times to complete trials has been shown during acquisition of matching-to-sample (Lydersen and Perkins, 1974), but ap-

Fig. 5. Choice accuracy across successive 15-sec intervals on FR schedules for each bird. The functions for each condition were continued until three successive intervals contained fewer than 10 trials. The performance on these three intervals and any later trials were placed to the extreme right of each panel.

Fig. 6 Top panels: the number of FR 10 and FR 20 trials per correct choice across successive correct choices for Bird C1. Bottom panels: the number of FR 10 and FR 20 trials within successive 15-sec intervals for Bird C1. See Figure 5 for criterion for discontinuing each function.

parently has not been examined during intermittent reinforcement of matching.

This explanation does not account for why any patterns of choice accuracy occur at all on FI and FR schedules. It has been shown that errors tend to follow pauses in responding both on conditional discrimination performances (*e.g.*, Ferster, 1960; Nevin *et al.*, 1963) and on simultaneous discrimination performances (*e.g.*, Nevin, 1967; Zeiler, 1968, 1970). Zeiler's (1968) suggestion that whatever controls pausing also controls errors is consistent with the present data. Precisely what controls both pauses and errors remains to be determined.

An alternative explanation, not necessarily incompatible with the above, involves the observation that the form of the accuracy patterns are reminiscent of the frequency functions of adjunctive behaviors found on a variety of reinforcement schedules. That is, the lowest accuracy occurred at about the same point in time between reinforcements that the highest frequency of adjunctive behaviors occur (*e.g.*, Killeen, 1975; Staddon and Simmelhag, 1971). Thus, it is tempting to speculate that perhaps the lowered accuracy is due to the occurrence of competing adjunctive behaviors.

Boren and Gollub (1972) reported that intermediate rates of matching were asso-

ciated with more errors than were high or low rates on FI schedules. The present results agree with Boren and Gollub's findings. However, changes in rates were also closely associated with postreinforcement pausing. That is, rates during the first 15-sec interval were low not because of low rates *per se*, but rather because the postreinforcement pause typically extended through this interval. Similarly, the increase in rate in subsequent 15-sec intervals also was not due to increases in running rate, but rather occurred because less of the time contained postreinforcement pausing. The high rate of errors toward the middle of FIs was most likely due to the fact that errors tended to follow immediately after the postreinforcement pause which, in turn, typically terminated toward the middle of FIs (*i.e.*, the portion of FIs associated with intermediate rates). Thus, although rate is an important index of schedule control, it does not provide a "... more detailed and informative way ..." (Boren, 1973) of analyzing matching than does choice accuracy.

A final point to be considered is that the similarity in performances produced by FI and FR reinforcement suggests that the same variable controlled both performances. However, this experiment did not permit any conclusion regarding a specific source of control. Both the number of responses (*e.g.*, Crossman, Heaps, Nunes, and Alferink, 1974; Rilling, 1967) and time (*e.g.*, Killeen, 1969; Lydersen and Crossman, 1974; Neuringer and Schneider, 1968) have been implicated.

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