POST-REINFORCEMENT PAUSES AND RESPONSE RATE OF MONKEYS ON A TWO-HAND FIXED-RATIO SCHEDULE¹

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Fixed-ratio behavior of monkeys was analyzed separately for two hands. While one hand responded on the fixed-ratio schedule the other performed a holding response and the function of the hands changed in alternate ratio runs. After performance was stable on the fixed ratio (70 responses, two monkeys; 100 responses, two monkeys, 120 responses, two monkeys) 90 sessions of further training equalized post-reinforcement pauses and the mean interresponse time of the two hands. Hand preference in reaching for food remained unchanged. Then, the fixed-ratio requirement was changed (a) in small sequential steps, (b) in two large steps, and, (c) within sessions alternating two runs at a high ratio with two runs at a low ratio. The mean duration of post-reinforcement pauses was correlated with a fixed ratio maintained throughout a session but single pauses were neither controlled by the immediately preceding nor by the following ratio run when a cue to its length was available. The mean interresponse time was insensitive to changes in fixed ratio. The fixed-ratio performance was generally similar to that of pigeons and rats.

Schedules of reinforcement with a high fixed ratio (FR) have been found to be associated with long post-reinforcement pauses when the ratio was changed in a large step (FR 160, FR 35, FR 140; Ferster and Skinner, 1957), increased in intermediate steps (FR 50, FR 75, FR 100, FR 150; Felton and Lyon, 1966) and changed sequentially in small steps (FR 15, FR 20, FR 30, FR 40, FR 160, FR 10; Powell, 1968). When pairs of runs at a low ratio (FR 20, green keylight) alternated with pairs of runs at a higher ratio (FR 40, or FR 50, red keylight) the pauses were longest after short, before long ratio runs (Mintz, Mourer, and Gofseyeff, 1967), indicating that the birds probably did not pause to rest; a contrast effect was suggested by the authors. The long pauses may reflect the aversive properties of the higher ratio schedule.

The effect of increased ratio requirements on running response rate is uncertain. Both increased (Kaplan 1956) and decreased (Winoograd 1965) rates were observed when reinforcement was negative and also positive reinforcement was associated with both increases (Boren, 1961) and inconsistent decreases in

rate (Felton and Lyon, 1966, Powell, 1968). In contrast, running response rate on fixed-ratio schedules is unaffected by the level of deprivation (Ferster and Skinner, 1957, Sidman and Stebbins, 1954), punishment (Azrin, 1959), and the duration of escape reinforcement (Azrin, Holz, Hake, and Ayllon, 1963).

In the present investigation, different fixed ratios were studied using positive reinforcement in monkeys; previous studies were on pigeons and rats. In preliminary experiments with one response lever, the monkeys often changed hands and this changed the response rate. To eliminate this behavior, two levers with concurrent contingencies were used. Reinforcement after repetitive fixed-ratio responding on one lever was contingent upon steady depression of a second lever and the contingencies of the two levers were changed in alternate ratio runs. Post-reinforcement pauses and running response rate (mean interresponse time; IRT) were measured during small and large changes in fixed-ratio size and during alternate pairs of runs at a high and a low ratio.

METHOD

Subjects

Six African, green monkeys, (*Cercopithecus aethiops*) adolescent males, weighed between 4.4 and 5.0 kg; this was their first experiment.

¹The work was partially supported by grants A 7/66, 511-84-1/69, and 511-701 from the Danish Science Advisory Council. Reprints may be obtained from the author, Institute of Neurophysiology, Juliane Maries Vej 36, DK-2100 Copenhagen, Denmark.

Apparatus

The experimental cage was 32 in. long by 20 in. wide by 24 in. high (80 by 50 by 60 cm.) The cage was also used to transport the monkey to and from the home cage. During experiments it was attached to a panel containing two levers 10 in. (25 cm) apart and 12 in. (30 cm) above the floor of the cage. The levers were Plexiglas cylinders 1.75 in. (2 cm) in diameter and 3.75 in. (9.5 cm) long, each lighted from a 0.6-w bulb. When each lever was depressed with a force of 150 g (1.47 N) against a spring load it triggered a microswitch. Banana flavored food pellets of 1 g were delivered into a tray between the two levers. When cues to the size of the following ratio run were needed, a green light on the right side of the tray indicated a high and a red light on the left indicated a low ratio. The experimental room was 6 by 3 by 2.80 m, and was sound insulated. Each subject was observed continuously on closed-circuit television from an adjoining room containing the scheduling and recording apparatus.

Reinforcements and responses of each hand with and without the holding response were recorded by cumulative counters, an event recorder, and a cumulative recorder (Ralph Gerbrands Co.). Interruptions of the holding response were also counted. Pauses after reinforcements were measured by cumulative counters driven by one pulse per second. The counters were stopped by the fourth rather than the first response after reinforcement because the monkeys generally made a few single responses before they started a stable sequence of responses. Histograms of interresponse times were photographed from the oscilloscope of a Nuclear Chicago 7100 computer using 400 data points.

Procedure

Depression of one of the levers lit the bulb in the other lever for as long as the first was held down. Responses on the second lever in the presence of the light were followed by pellets delivered on a fixed-ratio schedule. The contingencies on the levers were reversed after each pellet delivery. The FR was not reset by interruption of the depression of the other lever.

Training was conducted in stages. (i) Pressing the lever with the lighted bulb was rein-

forced; the levers were illuminated alternately. (ii) Pressing one lever illuminated the other lever and one response on this was reinforced. Early in training, the light and the reinforcement schedule on the second lever remained for 1 sec after the first lever was released. This *off-delay*, which facilitated training, was gradually reduced to zero. (iii) The monkey was required to press the lighted lever at a fixed ratio gradually increasing to 4. At this stage, all monkeys responded on both levers in synchrony. (iv) To reinforce steady depression of one lever and concurrent FR responses on the other lever, an *on-delay* was introduced. Depression of one lever illuminated the other after a brief delay, which was increased gradually to 1 sec and maintained throughout the experiment. One monkey had a tendency to perform the holding response with a foot. By manually turning off the light in the lever and withholding reinforcement this undesired response was eliminated. The monkeys did not attempt to operate the levers with crossed hands. (v) The FR was raised in steps of from 20 to 30% to 100 responses for Monkeys 16 and 18, to 70 responses for Monkeys 27 and 45, and to 120 responses for Monkeys 40 and 47. The number of sessions at each step was not fixed; the FR was raised whenever the monkey ceased to pause during ratio runs throughout a session. Stable performance at the final ratio was achieved after 79 to 108 sessions. After further training equalizing the performance of the two hands, FR was increased and decreased in small sequential steps (FR 52, 80, 100, 120, 140, 160, 180, 200, 180, 160, 140, 120, 100, 80, and 52) for Monkeys 27 and 45, each step being maintained for three sessions. The low ratio was maintained for 10 sessions and it was then increased and decreased in large steps for Monkeys 27 (FR 72, 320, 72) and 45 (FR 52, 200, 52), the high ratio being maintained for five sessions. Monkeys 27 and 45, and Monkeys 40 and 47, without previous experience of changes in FR, were subsequently trained on a schedule having two runs at a high ratio (FR 140, 160, or 200) alternating with two runs at a low ratio (FR 40). Within a session, one hand performed immediately before, the other after the ratio change. The association was reversed in the next session and 25 consecutive sessions were studied.

The monkeys were trained five or six days per week. During initial training, 40 pellets

per session and no food between sessions was found to maintain growth and good physical condition and to provide a suitable level of deprivation. Water was available at all times.

Hand preference was measured by letting the monkey reach out for pieces of fruit between the bars of a cage. The pieces of fruit were offered on a wooden board 14 by 8 in. (35 by 20 cm) placed along the middle of a side of the cage, a different side each day. The fruit was placed in the middle, to the right, or to the left of the board in a predetermined random sequence. There were intervals of 5 min between 10 daily trials for 10 successive days. The hand preference of each monkey was tested before FR training and again when the two hands produced the same histograms of inter-response times.

RESULTS

A. Differences in Performance of the Hands

Of the six monkeys, five preferred the right hand for reaching both before and after training involving 300,000 repetitive responses with each hand (Table I). One, preferring the right initially, used the hands equally after training.

1. *Interresponse times (IRT)*. After about 60 sessions of training at the final fixed ratio of FR 70 or FR 100, the mean IRTs were the same with the two hands in all monkeys. The initial differences were 10 to 15%, as illustrated for three monkeys in Figure 1. The preferred hand was not consistently the fastest and in one (16, Figure 1), the most rapidly responding hand changed from right to left after 18 sessions at FR 100.

Slowing towards the end of the sessions was absent, although 3000 to 4000 responses were made with each hand.

The interval histograms (inset, Figure 1) resembled normal distributions with standard deviations less than 0.05 sec ($n = 4000$). The peak of the distribution may be read accurately from the histograms to 0.1 sec. Since the distributions are symmetrical, the peak coincides with the mean and median.

2. *Post-reinforcement pauses (PRP)*. The amount of training that made mean IRTs the same with the two hands also equalized PRPs in all monkeys (Figure 2; the Wilcoxon signed ranks, matched pairs test, Wilcoxon, 1947). Initially during training at the final fixed ratio, there was considerable individual variation, as illustrated in Figure 2, where each column represents the mean of from 700 to 2000 PRPs. After ratio runs with the left hand, Monkey 18 paused five times longer than after runs with the right. Monkey 27, at the other extreme, paused equally after runs with the two hands throughout training at FR 70. The difference in the mean duration of the pauses was not consistently related to the hand preferred in reaching.

3. *The concurrent holding response*. The steady response was interrupted one to five times during each ratio run (Figure 2). The interruptions were fewer after long training but they did not disappear. Differences between the hands remained without a consistent relation to the hand preferred in reaching.

Thus, long training made the two hands perform the repetitive response with the same mean IRT and mean PRP. This equalization required training in excess of the amount nec-

Table 1

Hand preference before and after extensive FR training had equalized interresponse-time distributions produced with the two hands with probabilities of chance occurrence of the change.

Monkey		16	18	22	27	45	47
Use of the right hand as per cent of trials	Before FR-training	80	99	97	77	77	55 ^a
	After FR-training	91	99	80	53 ^a	74	47 ^a
Matched pairs signed ranks test. p		>0.1	>0.1	>0.1	=0.05	>0.1	>0.1

^a $p > 0.2$. The probability of chance occurrence of a difference between the other entries in the table and 50% is less than 0.001.

Fig. 1. Mean interresponse times (IRT) for the right (R, filled circles) and left (L, open circles) hand were different when stable behavior on the final fixed ratio was achieved. The preferred (right) hand did not consistently respond with the lowest mean IRT. Sixty sessions of further training made the two hands respond with the same mean IRT. Inserted are examples of histograms from which IRTs were read. The sessions were counted from the first day at the final ratio. Horizontal bars 0.2 sec. Vertical bars: 200 responses.

Fig. 2. When the behavior was stable on the final fixed ratio of 70 or 100, two monkeys with strong hand preference (Table I) made shorter pauses after fixed-ratio responding with the preferred (right) hand. Extensive training eliminated the difference. The hand difference in interruptions of the concurrent holding response was not consistently related to the preferred hand and it was not abolished by extensive training. The columns indicate means of 500, bars indicate mean errors. Probabilities of chance occurrence (p) were calculated using Wilcoxon's matched pairs, signed ranks test.

essary to achieve stable behavior, as judged from the cumulative record.

B. Small Sequential Changes in FR

1. *Interresponse times.* The changes in fixed-ratio size were correlated with mean IRT for only one hand in one monkey. In Monkey 45, the correlation coefficient τ (Kendall, 1948) calculated for the whole period of 15 sessions was 0.01 for the right and 0.03 for the left hand ($p > 0.1$). A correlation between mean IRT and fixed ratio size was absent for the right hand in Monkey 27 ($\tau = 0.02$; $p > 0.1$); for the left it was significant ($\tau = 0.21$; $p < 0.01$). The mean IRTs decreased with continued training; correlating mean IRT with successive sessions τ for the right hand was 0.75, for the left 0.96; $p < 0.01$ (Figure 3).

2. *Post-reinforcement pauses (PRP).* In both

monkeys, the pauses were longer the higher the ratio. The effect was most pronounced in Monkey 45. Each point of the curve in Figure 3 represents the mean of the 60 pauses the monkey had the opportunity to make in three successive sessions; the correlation coefficient τ for the association between PRPs with FR in the 15 points of the curve is 0.88 for the right and 0.89 for the left ($p < 0.001$). In Monkey 27, the effect was weaker; τ calculated on the basis of 25 points was 0.47 for the right ($p < 0.02$) and 0.38 for the left hand ($p < 0.05$). Handedness affected the results only in Monkey 45 and only during the rising phase of the ratio change. The increase in mean duration of the PRPs was associated with increased variability; the τ test used on FR and the standard deviation of PRPs ($N = 40$) showed that the correlation was high ($p < 0.001$).

Fig. 3. Small sequential changes in fixed ratio (FR) changed post-reinforcement pauses (PRP) but not mean interresponse times (IRT). The points on the IRT curve represent 2000 to 8000 responses from the last of the three days at each fixed ratio; mean errors were too small to be marked on the graph. The points on the PRP curve represent 60 pauses from the three sessions at the same ratio. Vertical bars indicate mean errors.

C. Large Changes in FR

In Monkey 45, the increase in fixed ratio from FR 52 to FR 200 was made two weeks after the end of the previous experiment and its behavior was stable both after the large increase and decrease in ratio. A very large increase from FR 72 to FR 320 in fixed ratio was presented to Monkey 27; it worked smoothly for about two-thirds of the number of reinforcements at the lower ratio and after that responded only intermittently. The session was ended after the first break in a ratio run lasting more than 5 min. No session ended with a PRP.

1. *Interresponse times.* An effect of the ratio change was absent (Figure 4) and, in contrast with the previous experiment (B), the result was clear for both monkeys. They responded with extreme regularity; the standard deviation of the distribution of IRTs was less than 100 msec and the mean error of less than 1.5 msec was too small to be marked on the graph (Figure 4). After the fixed ratio was returned to

the low value for Monkey 27, additional peaks in the IRT distribution occurred at lower and higher IRTs, indicating that the monkey now responded in a rhythm with three different IRTs. When retrained after a rest period of one month the IRT distribution was again unimodal.

2. *Post-reinforcement pauses.* The pauses lasted on the average two (Monkey 27) and five (Monkey 45) times longer in sessions with the higher ratio (Figure 4). The Mann and Whitney (1947) U-test applied to the points of the curve, each representing 20 pauses, showed that the change was highly significant ($p < 0.001$) for both hands in both monkeys. Post-reinforcement pauses changed gradually during the first session on the high FR (Figure 5) and there was a tendency to a more rapid change in pauses held after reinforcement of a response by the right (preferred) hand (Figure 4).

3. *Pairs of ratio runs alternating at a high and a low ratio.* The monkeys were trained for 50 consecutive sessions with a visual cue to the

Fig. 4. A large change in fixed ratio (FR) changed post-reinforcement pauses (PRP) but not mean interresponse times (IRT). Three peaks appeared temporarily in the IRT distribution when the FR was reduced, indicating that the monkey now responded in a rhythm with three different IRTs. The points on the curve represent the same as in Figure 3.

MONKEY 45

Fig. 5. Cumulative records showing that the change in post-reinforcement pauses elicited by a large increase in fixed ratio (FR) occurred gradually.

FR of the following ratio run. Table II contains the mean duration in seconds of the 250 PRPs from the last 25 sessions; the values of p were calculated using Wilcoxon's signed ranks, matched pairs test (Wilcoxon, 1947). For Monkey 40, PRPs were independent of the

TABLE 2

MEAN DURATION IN SECONDS OF POST-REINFORCEMENT PAUSES. 2 RUNS AT THE HIGH RATIO ALTERNATED WITH 2 RUNS AT THE LOW RATIO. PROBABILITIES OF CHANCE OCCURRENCE WERE CALCULATED USING WILCOXONS MATCHED PAIRS, SIGNED RANKS TEST.

MONKEY 40		FOLLOWING RUN	
		LONG	SHORT
PRE - CEDING RUN	LONG (FR120)	38.69	35.80
	SHORT (FR40)	39.76	35.38
		p > 0.1	p > 0.1

MONKEY 27		FOLLOWING RUN	
		LONG	SHORT
PRE - CEDING RUN	LONG (FR200)	24.54	26.18
	SHORT (FR40)	22.95	23.13
		p > 0.1	p < 0.001

MONKEY 47		FOLLOWING RUN	
		LONG	SHORT
PRE - CEDING RUN	LONG (FR160)	5.58	4.63
	SHORT (FR40)	5.71	5.90
		p > 0.1	p < 0.001

MONKEY 45		FOLLOWING RUN	
		LONG	SHORT
PRE - CEDING RUN	LONG (FR200)	24.35	21.65
	SHORT (FR40)	21.96	13.89
		p = 0.08	p < 0.001

length of the preceding run and shorter before a short run. Monkey 47 held very short pauses, especially after long, before short runs. Monkey 27 paused somewhat longer after long, before short runs, and Monkey 45 clearly made short pauses between two short runs. That two monkeys (27 and 45) were trained extensively on fixed-ratio schedules before this test did not affect the results. Calculated day-by-day, the differences were not significant.

In brief, PRPs were but slightly and inconsistently affected by the FR of the ratio run immediately before or after the pause; the observed differences varied individually.

DISCUSSION

The analysis of FR behavior showed that in general, the same relationship between FR, PRPs, and mean IRT obtains in monkeys as has previously been observed in rats and pigeons: PRPs increase with increasing FR and mean IRT is insensitive to changes in FR. Changes in PRPs elicited by a sudden change in FR occurred gradually in monkeys as well as in pigeons (Ferster and Skinner, 1957). Thus, the duration of a PRP was not controlled by the length of the ratio run immediately preceding it. A cue to the length of the following ratio run controlled the duration of PRPs in pigeons (FR 20, FR 20, FR 50, FR 50; Mintz, et al., 1967); in monkeys this control was weak and inconsistent.

A high fixed-ratio schedule may function as an aversive stimulus (Azrin, 1961; Appel, 1963; Thompson, 1965) and the PRP may be considered as a graded response to the aversive properties of the schedule. Fixed-ratio schedules may be more aversive in pigeons than in monkeys because in pigeons, the duration of PRPs was controlled by the length of a single ratio run; in monkeys more than a single run was required. Direct evidence on the extent of aversiveness of high fixed ratios in monkeys is not available.

The IRT distribution recorded in this study would reveal smaller changes than previous measures of response rate. Nevertheless, significant correlations with the FR requirement were generally absent. Response rate increased gradually during two to three months of daily training, then remained stable.

Extensive training was required to equalize the performance of the two hands. Early in

training, PRPs were shorter after reinforcement obtained by FR responding with the preferred hand (before FR responding with the non-preferred hand) and mean IRT was unequal but not consistently related to hand preference. About 60 sessions of further training eliminated these differences between the hands but failed to abolish a difference in the number of interruptions of a concurrent holding response.

The observations agree with previous reports that lateral preference in monkeys (Cole and Glees, 1951; Brookshire and Warren, 1962; Ettlinger and Moffet, 1964) may be pronounced, stable over many months, and resistant to change by training (Warren, Aplanalp, and Warren, 1967). The results reported here show, in addition, that hand preference in reaching for food may remain while differences in the performance of the two hands are eliminated by training.

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Received 7 April 1971.

(Final Acceptance 17 August 1971.)