EFFECTS OF RATIO REINFORCEMENT SCHEDULES ON DISCRIMINATION PERFORMANCE BY JAPANESE MONKEYS

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In Experiment 1, Japanese monkeys were trained on three conditional position-discrimination problems with colors as the conditional cues. Within each session, each problem was presented for two blocks of ten reinforcements; correct responses were reinforced under continuous-reinforcement, fixed-ratio 5, and variable-ratio 5 schedules, each assigned to one of the three problems. The assignment of schedules to problems was rotated a total of three times (15 sessions per assignment) after 30 sessions of acquisition training. Accuracy of discrimination increased to a moderate level with fewer trials under CRF than under ratio schedules. In contrast, the two ratio schedules, fixed and variable, were more effective in maintaining accurate discrimination than was CRF. With further training, as asymptotes were reached, accuracy was less affected by the schedule differences. These results demonstrated an interaction between the effects of reinforcement schedules and the level of acquisition. In Experiment 2, ratio sizes were gradually increased to 30. Discrimination accuracy was maintained until the ratio reached 20; ratio 30 strained the performance. Under FR conditions, accuracy increased as correct choice responses cumulated after reinforcement.

Key words: reinforcement schedules, fixed-ratio schedule, variable-ratio schedule, conditional discrimination, key press, monkeys

Previous work suggests that ratio reinforcement of discriminated behavior affects the accuracy of performance. First, ratio schedules control a particular sequence of correct and incorrect responses; namely, under fixed-ratio (FR) schedules incorrect responses occur more frequently during the early portions of the ratio run (with pigeons: Holmes, 1979; Mintz, Mourer, & Weinberg, 1966; Nevin, Cumming, & Berryman, 1963; Stubbs, 1968; Thomas, 1979; with human children: Davidson & Osborne, 1974). In contrast, accuracy of the discrimination is almost constant under variable-ratio (VR) schedules (Davidson & Osborne, 1974; Nevin et al., 1963).

Second, ratio schedules affect the overall accuracy of the discrimination. Concerning

this effect, previous results have not been consistent. For example, Ferster (1960) found that pigeons' matching-to-sample accuracy (with no intertrial interval) was near chance under a continuous-reinforcement (CRF) schedule but became higher as the fixed-ratio size increased to 20. Nevin et al. (1963) obtained the opposite results. In their experiment, matching-to-sample accuracy (with a 1-s intertrial interval) was highest with CRF. In order to resolve this inconsistency, Thomas (1979) tested pigeons' matching performance on FR schedules with and without an intertrial interval. Without an intertrial interval, he obtained results similar to Ferster's (1960). With intertrial intervals (larger than 5 s), however, accuracy was fairly constant for ratios from 1 (CRF) to 20, and these results were more like but not exactly consistent with those of Nevin et al. (1963). Similarly, accuracy was almost constant for ratios ranging from 3 to 10 in Davidson and Osborne's (1974) work with human children (without an intertrial interval). Thus, whether FR schedules improve

accuracy of discrimination is unclear.

Effects of VR schedules on discrimination have also been inconsistent. Nevin et al. (1963) demonstrated that accuracy was constantly high in comparison with FR schedules, but in Davidson and Osborne's (1974) data, accuracy on VR schedules was much the same as on FR schedules.

One aspect that has not been examined is the possibility of interaction between the effects of the reinforcement schedules and the level of acquisition; that is, a particular reinforcement schedule may be effective in increasing accuracy during acquisition (i.e., during the formation of the discrimination) but may be ineffective in maintaining accuracy after the discrimination is established. If such an interaction exists, performances on ratio schedules must be reexamined from this viewpoint.

A comparative perspective is also important. Although it is accepted that, in general, the effects of reinforcement schedules are replicable across species (e.g., Zeiler, 1977), their effects on discrimination have not been examined in many species. To evaluate the generality of the effect of reinforcement schedules, not only simple operants but also the discriminated performances of a variety of species should be examined.

The present study attempted to resolve some of these problems. Experiment 1 compared the effects of three reinforcement schedules (CRF, FR, VR) on the conditional discrimination performance of Japanese monkeys by tracing discrimination accuracy, in a within-subject design, from the beginning of training until the discrimination performance became stable. In Experiment 2, the temporal patterning of errors and the maximum size of the ratio that could maintain the discrimination were examined.

EXPERIMENT 1

In this experiment, Japanese monkeys were trained on three conditional discrimination problems involving pairs of colors, with each color in conditional relation to position of the reinforced response. Within sessions, each problem was presented for two blocks of 10 reinforcements, for a total of 60 reinforcements per session. A different reinforcement schedule (FR, VR, or CRF) was assigned to each problem. After establishment of the discrimination, the schedule assignments were rotated. With this procedure, the effects of each reinforcement schedule on the accuracy of discrimination during acquisition and maintenance were examined separately.

METHOD

Subjects

Three male Japanese monkeys, T441 (4 years old), T446 (4 years old), and T320 (6 years old) served. All subjects had extensive laboratory experience. Body weights of the subjects remained at about 95% of their free-feeding weights.

Apparatus

The experimental panel was attached to one wall of the chamber situated in a dark room to which masking white noise was supplied. Three transparent acrylic keys (35 mm by 50 mm) were arranged horizontally in the center of the panel, each key separated 70 mm center to center. In-line projectors (Industrial Electronics Engineers) could present seven colored lights (red: Kodak No. 25; purple: Fuji SP6; blue: Kodak No. 47A; bluegreen: Fuji BPB50; yellowgreen: Fuji BPB55; yellow: Fuji SC50; white: no filter) as stimuli on the keys. Eight small pushbuttons (21 mm by 27 mm) were below the keys, each button separated 35 mm center to center. The buttons could be illuminated independently. Only the center key and the two buttons at both ends were used. There was a houselight at the top of the panel; a feeding tray was located at the bottom of the panel. A universal feeder (Davis Scientific Instruments) served raisins in the tray as reinforcers. An electronic chime and a buzzer were outside the chamber. A minicomputer (Digital Equipment Corporation PDP8/f) controlled the equipment. Subjects' behavior was monitored with a TV camera.

Procedure

Preliminary training. The sequence of responding was initiated as follows. Trials started with lighting of the center key in white. Three responses on that key illuminated one of the two buttons at either end. A response on the illuminated button turned off the button and the light on the center key and was reinforced by a raisin accompanied by a 1-s electronic-chime sound. An intertrial interval of 0.5 s followed each trial. A session consisted of six blocks of 10 reinforcements. During sessions the houselight was always on except during blackout periods of 10 s that separated the blocks.

In the sixth session, ratio schedules of reinforcement were introduced. Correct response sequences (key press followed by appropriate button press) were reinforced under CRF in one block, under FR 5 in another block, and under VR 5 in the third block. Each of these three schedules appeared twice in a session. Correct responses that did not satisfy the schedule were followed by a short chime sound of 0.5 s (conditional reinforcement). Incorrect responses (responses on the unlit side button) did not affect the ratio counter and were followed by a 5-s timeout accompanied by a 1-s buzzer sound. Training continued until the subjects showed stable performances.

Phase 1. After the preliminary training, all subjects were trained on conditional position-discrimination problems (in the 12th session for T320 and T441 and in the 15th for T446). Trials started with presentation of a colored light on the center key. Three responses on that key simultaneously illuminated two buttons at both ends. A response on either button turned off the lights of the buttons and the center key. There were three discrimination problems, each involving a pair of colors. The correct choice responses were: left for red and right for bluegreen in Problem 1; left for yellowgreen and right for purple in Problem 2; left for blue and right for yellow in Problem 3.

In each problem, the correct choice responses were reinforced according to the reinforcement schedule (CRF, FR 5, or VR 5) that was assigned to the problem. The relations between the problem and the schedule were different between subjects and between phases, as summarized in Table 1. Consequences of correct responses that did not satisfy the schedule requirements, and the timeout punishment of the incorrect responses, were the same as in preliminary training. An intertrial interval of 0.5 s followed primary reinforcement, conditional reinforcement, or timeout. A new trial started after intertrial intervals (i.e., a noncorrection procedure was followed).

As in the preliminary training, sessions were divided into six blocks of 10 reinforcements, separated by 10-s blackout periods. Each problem randomly occupied one of the first three blocks and one of the remaining three. This phase was conducted for 30 sessions.

Phase 2. After Phase 1, 15 sessions were conducted with the relationship between the problem and the schedule altered as shown in Table 1.

Phase 3. After Phase 2, 15 sessions were conducted with the relationship further altered as shown in Table 1.

Phase 4. After Phase 3, 15 sessions were conducted in the same condition as Phase 1.

Table 1

Reinforcement Schedules Assigned to Each Problem in Each Phase of Experiment 1

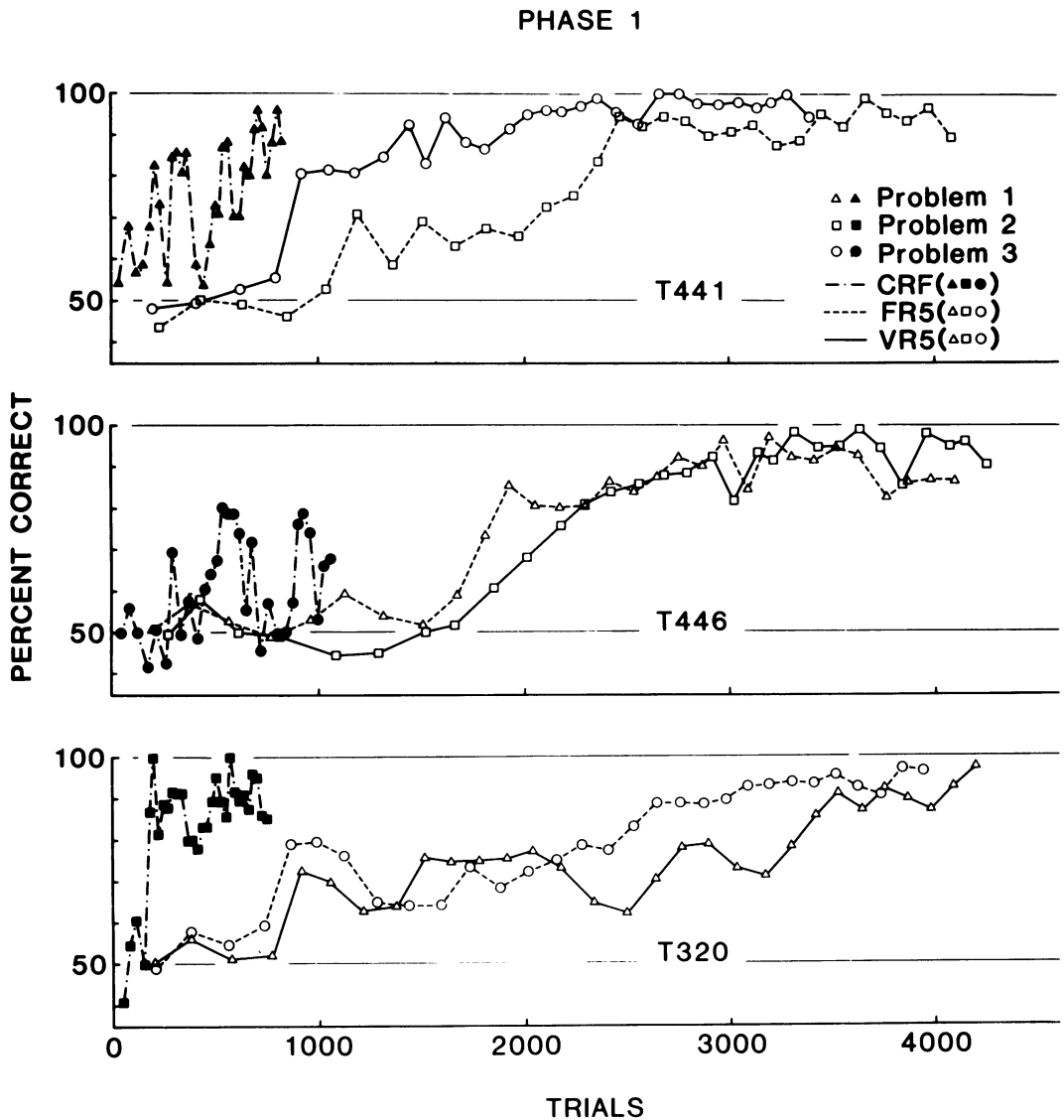| Monkey | T441 | | | T446 | | | T320 | | |
| Phase | Problem | | | Problem | | | Problem | | |
	1	2	3	1	2	3	1	2	3
Phase 1	CRF	FR5	VR5	FR5	VR5	CRF	VR5	CRF	FR5
Phase 2	VR5	CRF	FR5	CRF	FR5	VR5	CRF	FR5	VR5
Phase 3	FR5	VR5	CRF	VR5	CRF	FR5	FR5	VR5	CRF
Phase 4	CRF	FR5	VR5	FR5	VR5	CRF	VR5	CRF	FR5

PHASE 1

Fig. 1. The percentages of correct responses in all sessions of Phase 1 of Experiment 1 (vertical axis) are shown for each subject as a function of cumulative number of trials (horizontal axes). Symbols designate problems and lines connecting them correspond to the reinforcement schedules assigned to the problem. Symbols are filled when CRF was assigned to the problem. A symbol denotes a session—hence, 20 reinforcements for each problem.

RESULTS AND DISCUSSION

Figure 1 shows the percentages of correct responses in all sessions of Phase 1 for each subject as a function of the number of trials. Note that symbols are filled only when the schedule is CRF. The effect of the three reinforcement schedules on the formation of dis-

crimination can be seen by examining this figure. First, accuracy of all monkeys increased more quickly to a moderate level under the CRF schedule than under the other two schedules, although accuracy did not reach a constant level, especially for T446. The result suggests that the CRF schedule was much more effective in the
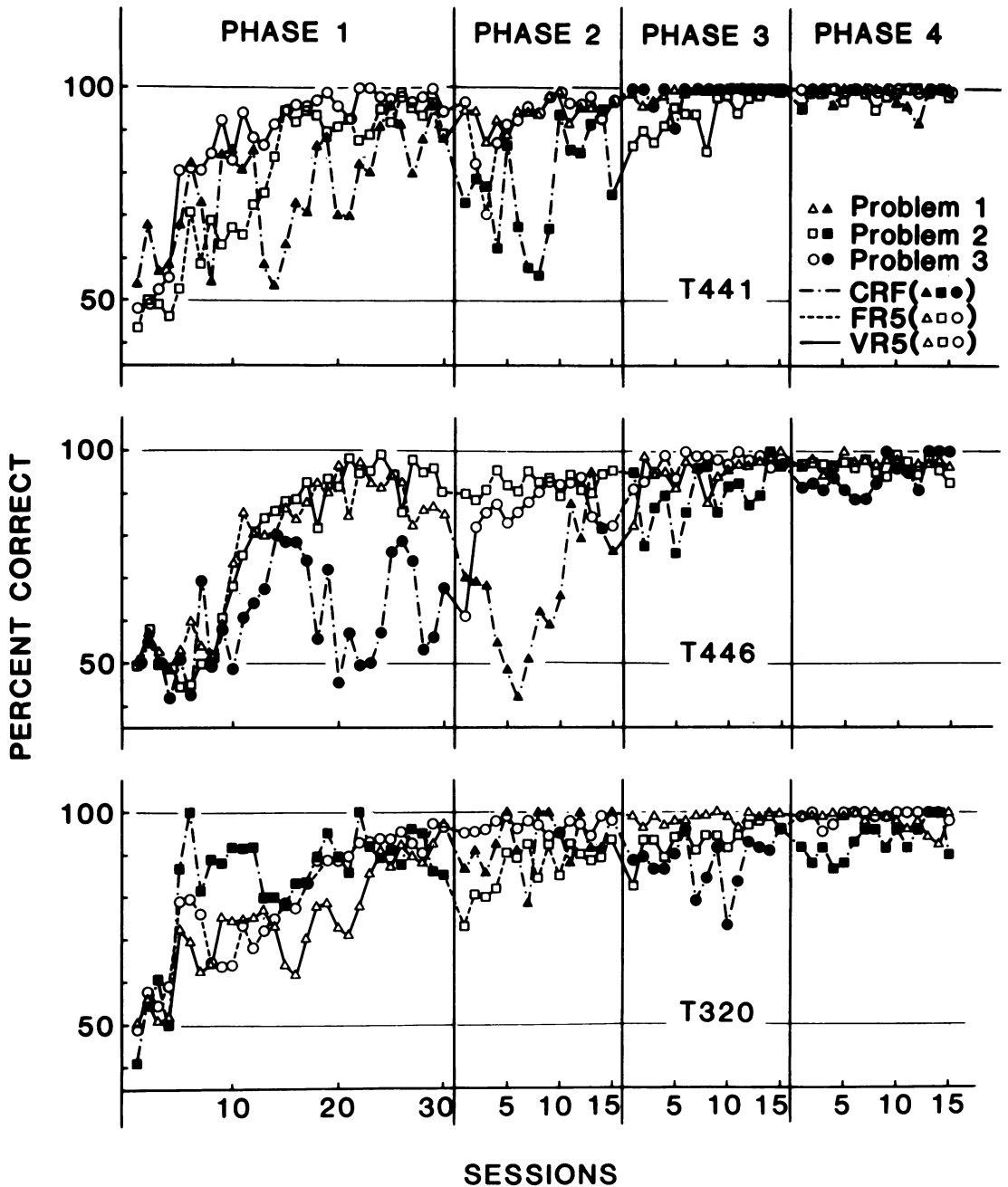
Fig. 2. The percentages of correct responses in all phases of Experiment 1. The horizontal axes show the numbers of sessions. Specifications of the symbols and lines are the same as in Figure 1. The assignments of the reinforcement schedules to the problems were rotated three times (Phases 2, 3, and 4) after the acquisition phase (Phase 1). See Table 1 for the schedule of rotation.

initial formation of the discrimination than were the FR and VR schedules. Second, the acquisition processes were not systematically different in the two ratio schedules; although T441 acquired the discrimination more rap-

idly under VR 5 than under FR 5, this was not the case for the other two monkeys.

Figure 2 shows the percentages of correct responses in all four phases of the experiment. The horizontal axes show the number

of sessions; symbols and lines are the same as in Figure 1. The effect of the three schedules on the maintenance of the discrimination can be examined in this figure. Subject T441, which reached about 80% correct for all problems in 5 to 15 sessions, maintained consistently high accuracy for two problems under FR 5 and VR 5 through Phase 1. In contrast, accuracy for the CRF problem repeatedly dropped to low levels for a few consecutive sessions. In Phase 2, in which the reinforcement schedule corresponding to each problem was rotated, accuracy under CRF deteriorated for several sessions. Thereafter, as the discrimination became asymptotic, accuracy was little affected by the schedule assignment.

The behavior of T446 was similar to that described above; only the performances under CRF repeatedly deteriorated. This monkey showed slight deterioration during the problems under CRF even in Phases 3 and 4, but this deterioration was much smaller than in the earlier phases. T320, whose performance was not consistent except for Problem 3 during Phases 1 and 2, showed behavior similar to that of the other two monkeys in Phases 3 and 4. Performances under FR and under VR were not systematically different in the three subjects during Phases 2, 3, and 4.

These results suggest that FR and VR schedules were of equivalent effectiveness, but were more effective than the CRF schedule in maintaining the discrimination once it was established at a moderate level. However, as Nevin (1967) found with simultaneous discrimination performances of pigeons, accuracy of discrimination was less susceptible to the effects of reinforcement schedules as the discrimination reached asymptote.

EXPERIMENT 2

Experiment 1 demonstrated that FR and VR schedules were effective in maintaining discrimination accuracy. The second experiment examined the maximum size of the ratio that would maintain the performance.

At the same time, the effects of ratio schedules on temporal patterning of errors were examined.

METHOD

Subjects

Two of the three monkeys in Experiment 1, T441 and T446, served as subjects immediately after Experiment 1. The third subject (T320) retired because his physical condition became poor.

Apparatus

The same equipment as in Experiment 1 was used.

Procedure

Immediately after the completion of Experiment 1, the sizes of the FR and VR schedules were repeatedly altered, while the relationships between the problems and the schedules were held constant. The constitution of a session was the same as in Experiment 1 except that each block ended when either 10 reinforcements or a 20-min pause in responding occurred.

In the initial phase of this experiment, 15 sessions were conducted with the size of the two ratio schedules increased to 10. Thereafter, 15 sessions were conducted with ratio 15, 15 session with ratio 20, and 10 sessions with ratio 30. Finally, 15 sessions were conducted with ratio 5.

RESULTS AND DISCUSSION

Figure 3 shows the percentage of correct responses with each problem (unfilled symbols) and the trial rate under each schedule (filled symbols) as a function of the ratio. Accuracy was almost constant up to a ratio of 15. At the ratio of 20, the trial rate was decreased, although declines in accuracy were slight. Performance was strained with the ratio increased to 30. Both subjects frequently emitted long pauses under this ratio, as is shown by the extremely low trial rates, and accuracy also decreased. Performances on FR and VR schedules of equal mean values were largely the same throughout Experiment 2. Only the trial rates produced by
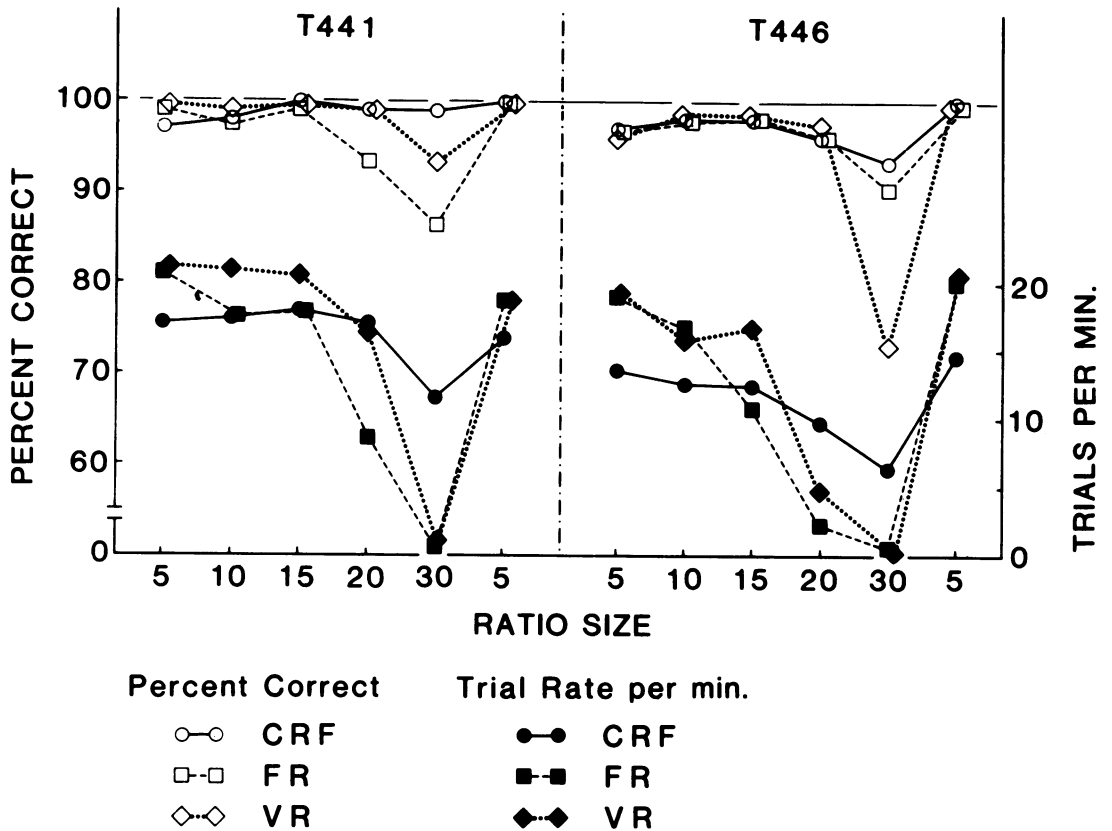
Fig. 3. Data for two monkeys used in Experiment 2. The percentage of correct responses for each problem (unfilled symbols) and the trial rate per minute (filled symbols) are shown as a function of the ratio size. The data show the total obtained in the last five sessions with each ratio size. The leftmost "5" indicates the last phase (Phase 4) of Experiment 1; the remainder are from Experiment 2.

FR schedules were a little lower than those produced by VR schedules. This difference is attributable to longer postreinforcement pauses in FR performances.

These results suggest that only ratio schedules smaller than 20, whether fixed or variable, maintain consistent responding and accurate discrimination. Thomas (1979) obtained similar results for matching-to-sample performance of pigeons. This may suggest that the maximum size of the ratio to maintain accurate performance does not differ greatly for simple conditional discrimination tasks such as matching to sample or the present one, without regard to species, reinforcers, etc. But, of course, different experimental conditions may produce different results. For example, Ferster (1958) reported that a chimpanzee maintained a simple re-

sponse-chain performance accurately up to FR 33. Also, the pigeons of Ferster (1960) maintained accurate matching performances under FR 47. Therefore, the maximum ratio obtained here was no more than an example.

Figure 4 shows the relationship between accuracy and the cumulative number of correct responses after reinforcement. Under the FR schedules (upper row), accuracy was low immediately after reinforcement and thereafter gradually increased. This trend was not so clear for smaller ratios but was remarkable for ratios 20 and 30. These results were consistent with previous studies with pigeons and humans (Davidson & Osborne, 1974; Holmes, 1979; Mintz et al., 1966; Nevin et al., 1963; Stubbs, 1968; Thomas, 1979). It is strongly suggested that the effect of fixed-ratio schedules on temporal patterning of er-
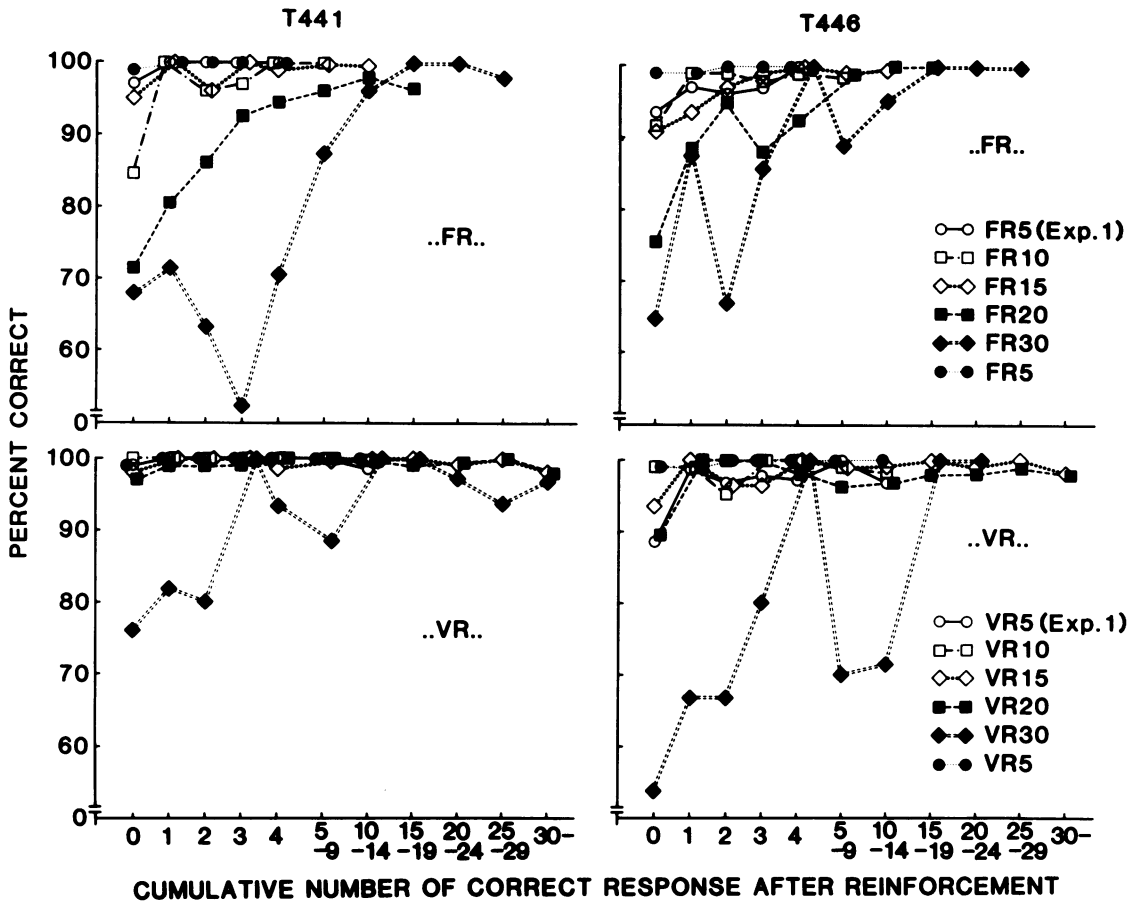
Fig. 4. The relationship between accuracy and the cumulative number of correct responses after reinforcement for each ratio schedule. The upper row corresponds to fixed-ratio schedules and the lower row corresponds to variable-ratio schedules. The data were calculated as totals of the last five sessions on each ratio size. The data for the first FR 5 and VR 5 (unfilled circles) are taken from the last phase (Phase 4) of Experiment 1; the remainder are from Experiment 2.

rors is consistent across animal species.

On VR schedules with values of up to 20 (lower row), accuracy for T441 was consistently high without regard to the number of correct responses after reinforcement. In contrast, T446 showed a slight decrease in accuracy immediately after reinforcement, as under the FR schedules. The result obtained from T441 may support the earlier findings with pigeons (Nevin et al., 1963) and humans (Davidson & Osborne, 1974), but this is not conclusive because of the results from T446 and those obtained under VR 30. On VR 30, the results from both monkeys were similar to those obtained under the FR schedules. This suggests that

on large VR schedules, errors occur soon after reinforcement. However, this is not conclusive because, as Figure 3 shows, performance on VR 30 was unstable and the absolute number of trials was small.

GENERAL DISCUSSION

The present study suggests that when considering the effect of a particular reinforcement schedule used in discrimination procedures, how far acquisition has progressed should be taken into account. With regard to the three schedules studied in the present experiments, a CRF schedule was more effective than FR and VR in producing increases in accuracy from chance level to moderate

levels. After accuracy of discrimination reached such levels, ratio schedules, fixed or variable, were more effective than CRF in maintaining accurate discrimination. As discrimination reached asymptote, there was little difference in the effect of reinforcement schedules on the accuracy of the discrimination.

The opposite effects of CRF and ratio schedules on acquisition and maintenance may be explained as follows: As the discrimination is formed by the difference in the rate of reinforcement, it is likely that the larger the absolute difference in the rate of reinforcement between correct and incorrect responses, the faster the discrimination will be formed. Hence the CRF schedule, which provides a large difference in the rate of reinforcement, is more effective in the formation of discrimination than are ratio schedules. On the other hand, intermediate levels of discrimination may provide subjects with a sufficiently high rate of reinforcement under CRF to prevent the discrimination from improving; hence the effectiveness of ratio schedules.

It is not clear whether the interaction demonstrated here is applicable to other animal species. However, the important suggestion is that specific results may depend upon specific testing procedures; the inconsistency among previous studies may be ascribed, at least in some part, to this interaction. For example, Thomas (1979) appears to have resolved the inconsistency between the studies by Ferster (1960) and Nevin et al. (1963) in terms of presence or absence of intertrial intervals. But his data may reflect the differing effects of ratio schedules in different acquisition stages. He first examined performances with no intertrial interval and found that accuracy was an increasing function of FR size. He then introduced intertrial intervals, obtaining fairly constant accuracy for ratios from 1 to 20. Although he ascribed these differences to the presence or absence of intertrial intervals, different learning stages may account for them. The decline in accuracy in the final return to CRF may be due to the removal of intertrial intervals.

Holt and Shafer (1973) reported that during both acquisition and maintenance, matching accuracy of pigeons under CRF was very low without intertrial intervals. As Thomas (1979) has suggested, this was probably due to a superstitious chaining of responses.

The findings of Nevin et al. (1963), which reported highest matching accuracy on CRF, may also be viewed as dependent upon asymptotic performance, inasmuch as their pigeons had much experience in matching to sample. Deteriorated accuracy on FR schedules seems to have been due to the absence of conditioned reinforcement. In the earlier stages of ratio reinforcement (e.g., FR 3 and FR 6), turning off the stimuli at the start of the intertrial intervals without a conditioned reinforcer, which was the same stimulus change as timeouts, may have punished correct matching responses just as timeouts punished incorrect responses (Ferster & Appel, 1961). In the later stages, prolonged matching training on ratio schedules may have sharpened discrimination between intertrial intervals and timeouts in terms of their duration, which may account for more accurate performances during later stages on FR 10 and VR 3 schedules.

Unfortunately, there are no direct data to determine whether these two interpretations based on the acquisition stage are appropriate. It is necessary to compare the effects of different ratio schedules directly using a multiple schedule as Ferster (1960) did between ratio and interval schedules.

Two other findings were obtained in Experiment 2. First, the maximum ratio size that was effective in maintaining the discrimination was 15 to 20. Thomas (1979) obtained similar results despite the differences in species, tasks, etc. But this does not necessarily mean that ratios of 15 to 20 are critical, because Ferster (1958, 1960) reported different results, as described earlier. Nevertheless, the data obtained here may provide a standard for comparison for other studies of discriminated performances of different species. Second, on FR schedules errors were frequent immediately after reinforcement and decreased as correct responses

cumulated. As noted earlier, similar results were obtained in pigeons and humans. Therefore, the effect of fixed-ratio schedules on temporal patterning of errors seems to be consistent among a variety of animal species.

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