AN APPRAISAL OF PREFERENCE FOR MULTIPLE versus MIXED SCHEDULES¹

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Pigeons' choice responses on either of two keys occasionally produced entry into a terminal link associated with that key. During the terminal links, responses produced access to grain according to mixed- or multiple-interval schedules. The multiple schedules provided stimuli correlated with the interval of time preceding reinforcement whereas the mixed schedules did not. The two subjects reliably preferred the multiple schedules to the mixed schedules throughout a series of replications. Preference for the multiple schedule was much smaller than suggested by earlier work comparing multiple and mixed schedules that had much higher rates of entry into the terminal links. Preference for the multiple schedule was greatly increased in this study when the rate of entry into the terminal schedules was increased. As in previous studies, these high preferences may have been the result of a sharp increase in the number of reinforcements on the multiple (as opposed to the mixed) schedule. The reliable but smaller preferences for the multiple schedule found with lower rates of entry into the terminal links were unconfounded by differences in the number of reinforcements obtained in the two terminal links.

A mixed schedule of reinforcement arranges reinforcers for responses according to several requirements, which vary unpredictably. A multiple schedule of reinforcement arranges reinforcers according to several requirements as in a mixed schedule, but a distinct exteroceptive stimulus is correlated with each requirement. Prokasy (1956) reported that rats preferred to run to a goal box that signalled the delay to reinforcement (the analogue of a multiple schedule) compared to another goal box with no stimulus correlated with the delay to reinforcement (analogous to a mixed schedule). Bower, McLean, and Meacham (1966), and Hendry (1969) performed experiments similar to Pro-

kasy's but using pigeons in a two-key operant test chamber. Two interval or ratio requirements alternated unpredictably. During the mixed schedule, the color of the response key was not correlated with the schedule requirement, but during the multiple schedule, the schedule requirements were correlated with different key colors. When both the mixed and multiple schedules were freely available, the pigeons chose the multiple schedule about 90% of the time. In other words, the subjects preferred the schedule providing stimuli correlated with the schedule requirements. Several other studies have demonstrated that a higher rate of responding is maintained by the opportunity to obtain reinforcers according to multiple schedules as compared to similar mixed schedules (Kendall, 1972; Wilton and Clements, 1971a). Wyckoff (1952) showed that the stimuli in a multiple schedule can function as reinforcers.

All these studies provide *qualitative* demonstrations of the reinforcing properties of the schedule-correlated stimuli of a multiple schedule, but they do not provide adequate quantitative data which, for example, would permit a comparison of the magnitude of multiple-schedule preferences with preferences induced by other reinforcement parameters, such as delay or amount of reinforcement.

¹In conducting the research described in this report, the investigators adhered to the "Guide for Laboratory Animal Facilities and Care", as promulgated by the Committee on Revision of the Guide for Laboratory Animal Facilities and Care of the Institute of Laboratory Animal Resources, National Academy of Science—National Research Council. This research was supported by National Institutes of Health Grant 20752-01 to the University of California, San Diego, Edmund Fantino, Principal Investigator.

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ment. Bower *et al.* (1966) in their study of multiple *versus* mixed schedules used a choice procedure that was a combination of forced-choice trials (only one alternative available) and free-choice trials in which both alternatives were available according to concurrent fixed-ratio 1 (*conc* FR 1) schedules. This procedure, and the similar one used by Hendry (1969), yielded uniformly large preferences for the multiple schedules, which may not have been sensitive to the amount of difference between the mixed and multiple schedules. Even a slight difference between the schedules would be expected to produce a large preference because there was no contingency to maintain responding for the non-preferred alternative (*cf.* Fantino, 1969). Consequently, more choice trials terminated with multiple-schedule reinforcements, and the differential number of reinforcements very probably contributed further to the magnitude of the preference for the multiple schedule. The present study sought to avoid and assess this difficulty by determining choice for multiple over mixed schedules, both in conditions where the relative rates of reinforcement did and did not vary as a result of choice.

The present study used a choice procedure that can provide a quantitative measure of the relative strengths of multiple and mixed schedule alternatives that is unconfounded by differential rates of reinforcement. This method, concurrent-chains with variable-interval (VI) initial links (equal to or greater than 1 min), has provided sensitive measurement of other variables such as delay-of-reinforcement, number of reinforcements, and required rates of responding (see Autor, 1969; Davison, 1972; Fantino, 1967, 1968; Herrnstein, 1964*a, b*; Hursh and Fantino, 1973; Killeen, 1968). In the concurrent-chains procedure, a pigeon responds on two concurrently available response keys. Responses on each key occasionally produce the stimulus associated with the terminal link of the chain on that key according to equal VI schedules of reinforcement. When either terminal link is entered, the other key becomes dark and inoperative. Responding in the terminal link produces primary reinforcement according to some schedule. The sequence on each key is a chain; the distribution of responses in the concurrent initial links (choice responses) is

an index of the relative values of the mutually exclusive terminal-link schedules. In this experiment, the terminal link was a combination of two different intervals occurring in a mixed or multiple schedule. Responding maintained by the mixed and multiple schedules was directly compared at various values of initial- and terminal-link schedules.

METHOD

Subjects

Two White Carneaux pigeons (Birds 2769 and 2733) were both naive before preliminary work on this experiment. Nine months of experience with a similar concurrent-chains procedure preceded the conditions reported here. The subjects were maintained at $80\% \pm 5\%$ of their free-feeding body weights at the start of the experiment.

Apparatus

A standard experimental chamber (Ferster and Skinner, 1957) contained a solenoid-operated grain hopper (Ralph Gerbrands Co.) centrally located in the lower portion of the front wall, two 6-W lamps mounted behind the front wall above the hopper opening (hopper lights), two 6-W lamps centrally located on the ceiling opposite the front wall (houselights), and two translucent response keys (Ralph Gerbrands Co.) centrally located on the front wall, 4-in. (10.2 cm) apart and 8.5 in. (21.6 cm) above the floor. The two keys could be transilluminated by four 7-W lights (Christmas tree bulbs) colored with red, blue, or green. The response keys could be operated by a minimum effective force of 15 g (0.15 N) and could produce an audible click from a relay mounted behind the front wall. To reduce extraneous light and noise, each chamber was completely covered by a plywood shell and received white noise during experimental sessions. The chambers were located in a dark room and connected via cables to scheduling and recording equipment in the adjacent room.

Preliminary Study

Although a full report of the preliminary work is not included, the general procedure and findings are reported here because they influenced the subsequent design of the experiment. Four subjects served, Birds 2769

and 2733 (the subjects of this experiment) and two others. In all conditions, the terminal-link schedules on the left and right were identical. The colors occurring on the keys were not, however, always the same. It was found that when the terminal-link key colors were not comparable, stable preferences as high as 76% were observed. This phenomenon suggested that terminal-link key color could influence preference and that a necessary precaution in subsequent work would be to maintain comparability between the two terminal links with respect to key color, especially since the effects of multiple-schedule stimuli upon choice may be small. In addition to controlling for color bias, the experiment reported below used only the two birds (2769 and 2733) that did not show color preferences during the preliminary observations.

Procedure

The concurrent-chains procedure is diagrammed in Figure 1 and is similar to that of Hursh and Fantino (1973). At the start of each session and after each terminal-link period throughout the session, the two response keys were lighted white. A separate VI schedule was associated with each white key, and occasionally the VI schedule arranged for a response on the key to initiate a terminal-link period. The VI schedules associated with each key during the initial links scheduled opportunities to enter the terminal link on that key every 60 sec or 15 sec (VI 60-sec or VI 15-sec), according to the conditions in Table 1. The probability that the next terminal link was scheduled was roughly constant as time elapsed since the last obtained terminal link on that key. When either of the VI schedules timed an interval, that timer stopped and arranged for a terminal-link entry on that key. The entry was produced by the next response on that key and resulted in: (1) changing the keylight from white to a color, (2) starting the terminal-link schedule, (3) darkening the other keylight and stopping its associated VI timer.

The VI initial-link schedules did not require equal exposure to the terminal-link schedules. When one VI arranged an entry into a terminal link it stopped timing until a response was made to the associated key. As time elapsed with the VI stopped until the appropriate key peck (set-up time), the overall rate

Fig. 1. The concurrent-chains procedure: in the initial links, responses on either key produced a terminal link according to *conc* VI 60-sec (or *conc* VI 15-sec) schedules. During either terminal link, the first peck after one of two randomly alternating intervals produced grain. Each component, x and y sec, occurred equally often. When the terminal link was associated with a multiple schedule, the shorter delay occurred during a red key and the longer during a green key. When the terminal link was associated with a mixed schedule, the same intervals occurred, and the key color was randomly alternated between red and green, but the color was uncorrelated with the intervals.

of terminal-link entries on that key was reduced. With extreme preferences on short VI schedules (e.g., VI 15-sec) the rate of terminal-link entries on the non-preferred key can be less than the rate on the preferred key producing relatively less exposure to the non-preferred terminal link. In practice, VI 60-sec schedules tend to provide more uniform entry to the terminal links than do VI 15-sec schedules.

The terminal-link schedules are diagrammed in Figure 1. One terminal link was a multiple schedule (*mult*). The values of the two component intervals were varied as shown in Table 1. The shorter interval was always associated with a red key and the longer interval with a green key. The other terminal link was a mixed schedule (*mix*) composed of intervals comparable to those occurring during the multiple-schedule terminal link. To maintain similarity between the two terminal links with respect to key color, half the time the key

color associated with the mixed schedule was red and half the time it was green. The mixed-schedule key color was not related to the size of the interval schedule in effect, however.

Sessions were conducted six days a week and were terminated following 40 reinforcements, after which all the chamber lights were extinguished and the keys were inoperative. Each condition was in effect for a minimum of 18 sessions and was terminated when the distribution of responding on the concurrent white keys met a day-to-day stability criterion applied to the last nine sessions: the nine sessions were divided into three groups of three sessions each and the mean of the three choice proportions in each group was determined; to satisfy the stability criterion, these three group means (M_1 , M_2 , M_3) could not span a range greater than 5% (0.05) and the means could not show a consistent increasing or decreasing trend ($M_1 < M_2 < M_3$ or $M_1 > M_2 > M_3$).

The baseline condition was conducted first to assess the extent of uncontrolled key preference. The concurrent initial-link schedules were VI 60-sec. For Bird 2769, the terminal-link schedules were both *mix* 10, 60-sec with red terminal-link keys. For Bird 2733, the terminal links were simple FI 60-sec schedules associated with green keys. The next condition was a comparison of mixed schedules and multiple schedules with VI 60-sec initial links (see Table 1). During the next two conditions, the initial-link schedules were shortened to VI 15-sec. The terminal-link schedules described in Table 1 were studied.

The next two conditions replicated the immediately preceding conditions with the multiple and mixed schedules reversed in the left and right terminal links. The last three conditions replicated the first two conditions with VI 60-sec initial links, but with the terminal-link schedules reversed on the keys. The last of these conditions was a baseline with two mixed schedules occurring in the terminal links and key colors of red and green occurring uncorrelated with the interval sizes.

RESULTS

The results are summarized in Table 1. All values are averaged over the last five sessions in each condition. During the initial baseline condition, neither subject showed any appre-

ciable key preference. When the terminal links were changed to mixed *versus* multiple schedules, Bird 2733 developed a 71% preference for *mult* 30 180-sec but Bird 2769 remained indifferent to the *mult* 10 60-sec and *mix* 10 60-sec schedules.

Since previous demonstrations of preference for multiple schedules had used shorter initial links (Bower *et al.*, 1966; Hendry, 1969), the initial links were shortened to VI 15-sec. As expected, Bird 2769 developed a 63% preference for *mult* 10 60-sec and Bird 2733 increased its preference for *mult* 30 180-sec to 94%. When the terminal-link intervals were changed from 10 and 60 sec to 30 and 180 sec for Bird 2769, and *vice versa* for Bird 2733, both subjects stabilized at still higher preferences for the multiple schedule, 73% and 100% for Birds 2769 and 2733 respectively.

The proportion of entries into the two terminal links tended to deviate from 0.50 with the VI 15-sec initial links (see Table 1). Bird 2769 entered the multiple terminal link 55% of the time when its choice proportion was 0.73, whereas Bird 2733 entered the multiple schedule 67% of the time when its choice proportion was 0.94, and 92% of the time when its choice proportion was nearly 1.0.

When the terminal-link schedules were reversed with respect to the left and right keys, both subjects reversed their preferences, demonstrating control by the multiple-schedule stimuli. These choice proportions, 0.69 and 0.76 for Birds 2769 and 2733 respectively, were not as extreme as the immediately preceding preferences and entries into the two terminal links were about equal. When the terminal-link intervals were changed again from 10 and 60 sec to 30 and 180 sec, and *vice versa*, choice proportions again increased for both subjects (to 0.84 and 0.90). The proportion of entries into the multiple schedule again deviated from 0.50 (0.57 and 0.56 for Birds 2769 and 2733 respectively).

When the initial links were lengthened to VI 60-sec, choice proportions consistently decreased. However, both subjects maintained a preference for the multiple schedule (choice proportions of 0.57 and 0.61 for Birds 2769 and 2733, respectively). Entries into the terminal links were equivalent for each key. After the terminal-link intervals were again changed, both subjects stabilized at higher choice proportions of 0.63 and 0.69. Finally,

Table 1

The initial- and terminal-link schedules, the position of the multiple terminal-link key (Left—"L"— or Right—"R"—), the choice proportion for the multiple schedule, the proportion of entries into the multiple terminal link, the absolute response rates (responses per minute) in the mixed (*mix*) and multiple (*mult*) initial and terminal links, the latencies to the third response (seconds) in the 60- and 180-sec delays in the *mix* and *mult* terminal links, and the number of sessions in each condition. Results are the means of the last five sessions of each condition. An asterisk (*) indicates baseline conditions with identical terminal links.

Subject	Initial Link VI (sec)	Terminal-Link Delays	Choice for mult	Proportion of mult Terminal-Link Entries	Initial Link: Resp/min				Terminal Link: Resp/min				Terminal Link: Latencies		Sessions
					mix		mult		mix		mult		mix	mult	
					Short	Long	Short	Long	Short	Long					
2769	60	10,60 (L)*	0.47	0.50	37.0	41.8	78.3	60.0	44.9	62.9	—	—	—	—	18
	60	10,60 (L)	0.46	0.52	51.3	43.1	53.8	70.4	56.7	52.0	3.6	18.0	3.6	18.0	53
	15	10,60 (L)	0.63	0.51	29.2	49.7	78.6	77.9	83.5	45.3	3.6	22.8	6.2	39.6	40
	15	30,180 (L)	0.73	0.55	18.7	50.2	87.4	93.5	84.2	70.6	6.2	39.6	6.2	39.6	64
	15	30,180 (R)	0.69	0.53	11.4	26.0	78.5	80.8	88.2	46.1	3.6	31.2	3.6	31.2	30
	15	10,60 (R)	0.84	0.57	11.1	57.4	83.2	86.4	101.2	46.3	1.8	17.4	1.8	17.4	18
	60	10,60 (R)	0.57	0.51	34.4	46.2	72.6	76.7	128.3	37.9	3.0	27.6	3.0	27.6	19
	60	30,180 (R)	0.63	0.50	24.1	41.6	75.0	78.0	81.6	53.5	5.4	43.2	5.4	43.2	18
	60	30,180 (R)*	0.50	0.51	20.1	20.6	54.6	60.8	60.5	70.7	4.8	8.4	4.8	8.4	34
	60	60 (R)*	0.52	0.50	27.6	29.8	68.9	64.2	64.2	64.2	—	—	—	—	34
2733	60	30,180 (R)	0.71	0.49	24.5	61.1	66.3	76.6	122.3	56.0	4.8	46.2	4.8	46.2	41
	15	30,180 (R)	0.94	0.67	5.76	92.8	74.4	74.8	151.7	57.6	4.2	45.0	4.2	45.0	27
	15	10,60 (R)	0.996	0.92	0.34	93.2	68.0	69.0	198.4	56.0	2.4	20.4	2.4	20.4	29
	15	10,60 (L)	0.76	0.50	18.4	59.5	81.2	77.2	200.5	43.8	2.7	24.6	2.7	24.6	47
	15	30,180 (L)	0.90	0.56	6.94	64.9	89.1	85.1	85.6	64.3	2.4	25.2	2.4	25.2	25
	60	30,180 (L)	0.61	0.51	33.1	52.0	92.5	83.0	152.5	54.4	3.6	44.4	3.6	44.4	25
	60	10,60 (L)	0.69	0.51	24.0	52.7	66.7	81.1	193.0	74.9	2.4	15.0	2.4	15.0	21
	60	10,60 (L)*	0.53	0.50	33.9	37.8	69.9	73.7	114.2	98.5	2.9	1.5	2.9	1.5	18

the multiple schedules were changed to mixed schedules and both subjects stabilized with no appreciable preference for the previous multiple-schedule key, *i.e.*, choice proportions of 0.50 and 0.53 for Birds 2769 and 2733, respectively.

The counterbalanced sequence of conditions demonstrated four findings summarized in Figure 2 and in Table 1: (1) both subjects consistently preferred multiple schedules to

mixed schedules; (2) shortening the initial-link VI schedules from 60 sec to 15 sec increased preferences in every case; (3) the size of the component intervals in the mixed and multiple schedules exerted no consistent influence over preference; generally, preference increased with additional sessions regardless of changes in the terminal-link durations; (4) the replications of each condition with each subject revealed an apparent preference correlated with the right key that ranged from 0.04 to 0.24 (see Table 1).

The response rates in the terminal links were similar for both subjects. In the mixed schedules, there was little discrimination of the component intervals and response rates were usually similar. Occasionally, response rates were higher in the *longer* (60 and 180 sec) components because pausing during the initial part of the intervals was not proportional to the duration of the intervals. In the multiple schedules, the component intervals were discriminated and rates in the shorter intervals (10 and 30 sec) were much higher than in the longer intervals (60 and 180 sec). The differences in response rates between the mixed and multiple schedules demonstrated that the stimuli correlated with these schedules controlled clearly distinct patterns of responding.

The latencies in the longer (60 and 180 sec) intervals provided more evidence that the subjects discriminated the components of the multiple schedule. In the mixed schedules, latencies of only a few seconds—appropriate to the lengths of the shorter components—occurred in both long and short components. In the multiple schedules, however, the latencies in the 60- and 180-sec components were much larger, on the average, exceeding the total length of the shorter components alternating with them.

DISCUSSION

The procedure reported here eliminated most extraneous factors present in previous studies. Under these conditions, multiple schedules were preferred to mixed schedules but the effect was found to be small when the initial-link schedules were *conc* VI 60-sec schedules. In fact, Bird 2769 failed to show the preference during its first exposure to the comparison. In relation to studies of several

Fig. 2. The mean relative response rate on the multiple-schedule key in the initial link averaged over comparable conditions of the experiment. The terminal-link schedules are shown under the bars. The left panels are with VI 60-sec initial links and the right panels are with VI 15-sec initial links. The top graph shows the average performance of Bird 2769 and the bottom graph is the average for Bird 2733.

other independent variables with concurrent-chain schedules (*e.g.*, Davison, 1972; Fantino, 1968; Herrnstein, 1964a; Hursh and Fantino, 1973; Killeen, 1968), the preference for multiple-schedule stimuli was relatively small.

The size of the initial-link schedules was shown to be a major factor controlling the magnitude of this preference, which suggests that the earlier reports of large preferences (85% to 99%, see Bower *et al.*, 1966; Hendry, 1969) were exaggerated by the very short FR schedules used as initial links. The short fixed-ratio schedules in the initial links produced a larger proportion of terminal-link entries on the preferred key and ensured that even a small preference for the multiple schedules would cause the number of terminal-link entries to favor the multiple schedules. The inequality of terminal-link entries could have further increased preference.

In the present study, this confounding was avoided by using *conc* VI 60-sec schedules. Obtained entries into each terminal link were about equal and the observed preferences were far less extreme, an average across conditions of 57% for Bird 2769 and 67% for Bird 2733 (see Figure 2). The preference determinations with the short VI 15-sec initial links, on the other hand, were considerably larger and the proportions of entries into each terminal link were unequal. This indicated that by simply shortening the initial links, preference can be increased, and often these preferences are further inflated because the number of terminal-link entries become unequal (*cf.* Fantino, 1969). This manipulation also increased the overall rate of reinforcement, but this factor does not appear to be responsible for the increased preferences: while overall rate of reinforcement was more than three times greater with VI 60-sec initial links and terminal intervals of 10 and 60 sec, than with VI 15-sec initial links and terminal intervals of 30 and 180 sec, preferences were far greater in the latter set of comparisons.

It is worth noting that the correlation between high preference and unequal entries into the multiple schedules was related, not only to the initial-link schedules, but also to the subjects. Bird 2733 had much higher preferences with VI 15-sec initial links than Bird 2769 and also had more disproportionate exposure to the multiple schedules.

This experiment was designed to assess the magnitude of the preference for multiple schedules with a variety of controls for extraneous factors and was comparable in design to previous studies using concurrent chains. A more detailed analysis of the phenomenon was premature until a sensitive quantitative method for measuring it had been developed. Wilton and Clements (1971a, b) and Kendall (1972) reported a procedure for studying multiple-schedule stimuli in the terminal link of a simple chain. Absolute response rate in the initial link was used to measure the reinforcement magnitude of the multiple-schedule stimuli relative to the baseline response rate determined without these stimuli. Multiple schedules did maintain higher absolute rates than mixed schedules; however, Kendall (1972) reported a failure to observe any effect of multiple-schedule stimuli with alternating delays up to 15 and 55 sec, observing a reliable affect only with delays of 15 and 120 sec. Wilton and Clements (1971a,b) utilized alternating reinforced and non-reinforced intervals. These findings suggest that the simple chain is somewhat less sensitive than the concurrent-chains procedure reported here, in which alternating intervals of 10 and 60 sec produced reliable preferences for the multiple schedule. Other investigators have reported the superior sensitivity of concurrent schedules compared to simple schedules when studying factors controlling magnitude of reinforcement (Catania, 1963; Davis, Davison, and Webster, 1972; Neuringer, 1967; Rachlin, 1967).

The present experiment demonstrated the high sensitivity of the concurrent-chains procedure while not obtaining a high degree of replicability. Preference under similar conditions varied by as much as 24% between replications. Two factors appeared to be correlated with this variance: (1) a relatively consistent preference for the right key, and (2) a tendency for preference to increase when only the terminal-link values were changed. It appears that the sensitivity of the concurrent-chains procedure, which made it particularly suitable for studying the relatively weak preference for multiple schedules, permitted other sources of extraneous reinforcement to influence preference as well. This feature of the procedure was offset by various tactics (controls for color bias, mul-

multiple baselines, reversals, and replications). Two conclusions are unequivocal: (1) multiple schedules were preferred to mixed schedules, and (2) this preference was modulated by the duration of the initial-link schedules; all preferences observed for a subject with VI 15-sec initial links were greater than the preferences observed with VI 60-sec initial links.

Future studies of multiple schedules with the concurrent-chains procedure could modulate the sensitivity of the procedure by manipulating the durations of the initial-link schedules between 15 and 60 sec. Some intermediate value may provide consistently measurable preferences (sensitivity) while avoiding the complications of unequal entries into the terminal links and the influence of extraneous sources of reinforcement.

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Received 7 June 1973.

(Final Acceptance 25 January 1974.)