SIGNALLED AND UNSIGNALLED PERCENTAGE REINFORCEMENT OF PERFORMANCE UNDER A CHAINED SCHEDULE¹

MARC N. BRANCH

UNIVERSITY OF FLORIDA

Pigeons were trained to peck a key under a chained fixed-ratio 15 fixed-interval 25-sec schedule of food presentation. In Experiment 1, blocks of sessions in which 100%, 75%, 50%, and 25% of the sequences ended with food presentation were conducted. When food presentation was omitted, a timeout of equal duration replaced it. As the frequency of food presentation decreased so did the frequency of completing the chained schedule. In Experiment 2, 75%, 50%, or 25% of the sequences terminated with food presentation and outcomes were signalled, *i.e.*, completion of the fixed ratio resulted in either a stimulus correlated with the fixed-interval 25-sec schedule or a stimulus correlated with extinction. As the frequency of food presentation decreased, the number of sequences completed per session increased for two pigeons and remained high for a third. In Experiments 3 and 4, assessments of the effects of signalling the outcome of the chained schedule were made with response-independent presentation of events at the end of the sequence. Again, signalling the outcome of the chained schedule led to more chains being completed per session than did not signalling the outcome. Stimuli differentially paired with food presentation have powerful behavioral effects that may be attributed to the potency of these stimuli as conditioned reinforcers.

Key words: percentage reinforcement, chained schedules, observing responses, conditioned reinforcement, key peck, pigeons

Traditionally, researchers studying intermittent reinforcement have employed small units of behavior, such as individual lever presses or key pecks. Recently, however, several investigators have explored intermittent reinforcement of larger, more complex units of behavior. Specifically, these researchers have treated performance under a schedule itself as a unit of behavior. For example, performance under a fixed-ratio schedule might be considered as a single unit of behavior. Under these circumstances, instead of presenting food after each completion of the ratio, the investigator would present food only after some of the ratios. Usually, when food presentation is omitted at the end of a schedule, some other

stimulus is substituted. Such schedules are often referred to as percentage-reinforcement schedules (Ferster and Skinner, 1957). They may also be considered as second-order schedules, according to the definition of Kelleher (1966).

Investigations of percentage reinforcement have included examination of fixed-ratio schedules as units (Ferster and Skinner, 1957; McMillan, 1971; Zimmerman, 1960), fixed-interval schedules as units (Allen, Porter, and Arazie, 1975; de Lorge, 1967; Neuringer and Chung, 1967; Staddon and Innis, 1969; Zeiler, 1972; Zimmerman, 1971), and variable-interval schedules as units (McMillan, 1971). A common outcome of experiments on percentage reinforcement is that a stimulus substituted for food presentation functions very much as food presentation does.

It is also possible to arrange intermittent reinforcement of even more complex sequences of behavior, such as behavior under chained schedules. A chained schedule is a compound schedule in which two or more simple schedules (components) must be completed in a fixed order, each simple schedule is associated with a distinctive exteroceptive stimulus, and

¹Research supported by Contract Number DAMD17-74-4085C from the U.S. Army Medical Research and Development Command and a Summer Research Grant from the Graduate School of the University of Florida. Manuscript preparation was aided by USPHS Grant No. 1 R01 DA 01417 from NIDA. The author wishes to acknowledge the technical assistance provided by D. M. Lee, D. S. Saunders, R. B. Scruggs, and D. Goodman, and the secretarial assistance of J. Brown. Reprints may be obtained from the author, Psychology Department, University of Florida, Gainesville, Florida 32611.

food presentation occurs only after the entire sequence has been completed. The consequence of satisfying the requirements of components other than the terminal one is presentation of the next component and its correlated stimulus (Ferster and Skinner, 1957). Marr (1969) presented grain to pigeons after every fifth completion of a chained fixed-interval 3-min fixed-ratio 30 schedule (chained FI 3-min FR 30), and Findley (1962) intermittently presented grain to pigeons after completion of a chained FR 10 FR 10 FR 10 schedule. Both investigators reported that chained-schedule performance was maintained and that the temporal patterns of responding were similar to those observed under conditions where food presentation occurs at the end of each sequence. The experiments reported here yield a quantitative description of the effects of intermittent reinforcement of performance under a chained schedule where several degrees of intermittency were examined.

Findley (1962) argued that by complicating behavioral samples under intermittent schedules of food presentation, we may learn about behavioral processes other than those that are a direct result of intermittent scheduling. The present experiments utilized this tactic to compare intermittent reinforcement of performance under a standard chained schedule with intermittent reinforcement of performance with a procedure where the response requirements were identical to those under the chained schedule, except that an exteroceptive stimulus signalled² whether or not completion of the chain would result in presentation of food. Specifically, the first component of a two-component chained schedule was a fixed-ratio schedule and the second a fixed-interval schedule. In the first experiment, completion of the fixed ratio resulted in presentation of the fixed-interval schedule and its associated stimulus; completion of the fixed-interval schedule intermittently resulted in the presentation of food. In the second experiment, completion of the fixed ratio resulted in one of two outcomes, *viz.*, either the fixed-interval schedule and its correlated stimulus (fixed-interval

stimulus) was presented, or another stimulus was presented. The fixed-interval stimulus signalled that food would be available at the end of the interval; the other stimulus was correlated with the absence of food at the end of the interval. Two subsequent experiments examined the effects of presenting events at the end of the chain independently of responding.

Some of the present procedures, in which events at the end of the chained schedule were signalled, are similar to a procedure used by Wilton and Clements (1971*a, b*). In one of their experiments (Wilton and Clements, 1971*b*), pigeons pecked a key under a two-component chained schedule in which the second-component stimuli signalled whether or not food would be presented at the end of the chain. They reported that rates of pecking in the first component were higher when food was presented following 20% of the chains than when 80% of the chains terminated with food presentation. They did not, however, compare the effects of presenting food 80% of the time *versus* 20% of the time under conditions where outcomes were not signalled, and were thus unable to conclude with certainty that the signalling procedure was responsible for the difference. The present experiments made such a comparison.

Another report that bears on questions examined by my experiments is one by Kendall (1974). Kendall used variants of the concurrent-chains procedure (*cf.* Autor, 1969) to determine preferences between conditions in which food presentation reliably occurred *versus* conditions in which food was intermittently presented, but also signalled. He reported several cases in which preferences for less frequent, but signalled food presentation were established. The present experiments made a similar comparison using a nonchoice procedure.

METHOD

Subjects

Three adult male, White Carneaux pigeons, numbered 4505, 5982, and 9401, were housed individually with continuous access to water and health grit except during experimental sessions. The pigeons, all experimentally naive, were maintained at 80% of their free-feeding weights throughout the experiments.

²The term "signalled" is used instead of "correlated" because the former is more restrictive, and thus more specific, in that it applies only to situations in which correlation is perfect.

Apparatus

Sessions were conducted in a pigeon conditioning chamber similar to that described by Ferster and Skinner (1957). The interior of the chamber was 30 cm wide by 31 cm long by 31 cm deep. The response key (R. Gerbrands Co.) was mounted behind a 2-cm diameter circular hole in an aluminum sheet that served as one wall of the chamber. The center of the key was 22 cm from the floor and 15.5 cm from either side wall. A static force of 15 g (0.15 N) or more on the key produced a brief (40 msec) click of a relay behind the wall and was counted as a response.

Access to a solenoid-controlled grain feeder was provided by a rectangular (6-cm by 5-cm) hole located 10.5 cm below the key. When the feeder was operated, it provided access to grain for 3.0 sec, and all lights in the chamber were extinguished, except for a 1.1-W lamp that illuminated the grain.

Indirect general illumination of the chamber was provided by two 1.1-W lamps in the upper corners of the aluminum wall. Each lamp had a reflector under it that deflected the light into the upper corners of the chamber. White masking noise was continuously present in the room where the chamber was located, and additional masking noise was provided by a ventilation fan on the chamber.

The first 343 daily sessions were monitored and controlled by electromechanical switching and timing equipment. During these sessions, a BRS/LVE probability generator (model 235-11) arranged probabilities. During the remaining sessions, a PDP8/f minicomputer utilizing the SKED process-control system controlled experimental events and recorded data. Throughout all sessions, responses were recorded on a cumulative response recorder (R. Gerbrands Co.). Recording and control equipment were located in a room adjacent to the one that housed the chamber, and power to the stimulus lights was provided by a supply independent of the one that provided power to the programming circuitry.

Procedure

Experiment 1. The pigeons were trained to eat from the food magazine and then successive approximations to a key peck were followed by access to grain until the pigeons pecked the key (lighted green). They were

then exposed to a series of chained fixed-ratio fixed-interval schedules, in which both the fixed ratio and fixed interval were gradually increased. The response key was lighted red during the fixed ratio and green during the fixed interval. After 58 sessions, all three subjects were placed under a chained fixed-ratio 15 (FR 15) fixed-interval 25-sec (FI 25-sec) schedule. The first session of chained FR 15 FI 25-sec was designated as the first session of the experiment.

After 36 sessions of exposure to chained FR 15 FI 25-sec, a percentage reinforcement program was instituted. Seventy-five per cent of the sequences (chains) ended with a peck that produced 3.0-sec access to grain, whereas the peck that terminated the remaining 25% of the chains produced a 3.0-sec period during which all lights in the chamber were extinguished (timeout). The pigeons were then exposed successively to procedures in which 50%, 25%, and 75% of the chains resulted in access to grain. The number of sessions that each condition was in effect is shown in Table 1.

Experiment 2. The second experiment began with 75% of the sequences terminating with food presentation. When a sequence was scheduled not to end with access to food, however, the fifteenth peck on the red key (fixed-ratio stimulus) changed the key to amber rather than green. After 25 sec, the amber light was automatically followed by a 3.0-sec timeout, after which the key was lighted red and the next sequence began. As in the first experiment, the percentage of chains scheduled to end with food presentation was varied to 50% and then to 25% (See Table 1). Thus, the second experiment differed from the first in that the outcome of the second component of the chained schedule (food presentation *versus* timeout) was signalled.

Experiment 3. The third experiment began immediately after Experiment 2, and was conducted as a control for one of the differences between Experiments 1 and 2. In Experiment 1, a key peck produced timeouts; in Experiment 2, these periods were presented independently of responding. The first phase of Experiment 3 nearly duplicated a condition of Experiment 1, in that outcomes were not signalled. When a timeout was scheduled, however, it was presented independently of key pecking. Experiment 3 began with 25% of the chains ending with response-dependent access

to food, *i.e.*, 25% of the time the first peck on the green key after 25 sec had elapsed produced access to grain. The remaining 75% of the green-key presentations were automatically terminated with a timeout *i.e.*, timeouts were not response-produced. After 17 sessions, the procedure was made identical to the last condition of Experiment 2, *i.e.*, 15 pecks on the red key produced either green (25% of the time) or amber (75% of the time). The first peck after 25 sec in green resulted in food presentation, and a 3-sec timeout was presented independently of responding after 25 sec of amber. This condition was kept in effect for 10 sessions. Thus, Experiment 3 compared responding under unsignalled and signalled conditions when all timeouts were presented independently of responding in the second component of the chained schedule.

Experiment 4. In Experiment 4, all events at the end of chains were presented independently of responding. The experiment began immediately after Experiment 3. In this experiment, 15 pecks on the red key produced either white or amber light behind the key. If white was presented, then after 25 sec, grain was made available for 3 sec. If amber was produced, then after 25 sec, a 3-sec timeout occurred. This procedure was designated a signalled percentage reinforcement of a chained FR 15 fixed-time 25-sec (FT 25-sec) schedule. Initially, food was presented after 50% of the sequences, but after 39 sessions the procedure was altered so that 25% of the chains ended with food presentation. After 106 sessions with this procedure, an unsignalled procedure was employed, under which 15 pecks on the red key always produced a white key-light. Twenty-five per cent of the times, the 25-sec white-key presentation was terminated with 3-sec access to food and 75% of the time with a 3-sec timeout. After 43 sessions, the signalled procedure was re-instated for 17 sessions. Experiment 4, then, compared responding under signalled and unsignalled conditions when both timeouts and access to food occurred independently of responding in the second component of the chained schedule.

During Experiments 1, 2, and 4, each condition was kept in effect until all three pigeons exhibited no significant changes in the number of chains completed per session for 10 consecutive sessions. Stability was determined by visual inspection. The stability criterion was vio-

lated twice during the first two experiments, and in both cases it was Pigeon 5982's behavior that was not stable when a change in percentage was made. In the first experiment, under the 25% condition, it appeared that Pigeon 5982 was going to stop pecking entirely, so, rather than choosing to have to re-establish key pecking, the percentage was changed to 75% before Pigeon 5982's performance stabilized. The other instance of not adhering to the stability criterion was occasioned by an injury (broken leg) to Pigeon 5982 after 29 sessions of exposure to the 50% condition in the second experiment. Instead of waiting for this pigeon to recover before proceeding to the next condition, the percentage was changed to 25% when the behavior of the other two pigeons was judged stable. When its leg had healed, Pigeon 5982 was re-introduced into the experiment at the new percentage, *i.e.*, 25%.

Throughout all four experiments, sessions were held daily, seven days per week, and a session was terminated following either the first food presentation or timeout that occurred after 60 min had elapsed since the beginning of the session.

RESULTS

Experiments 1 and 2

Figure 1 displays the major results of both Experiments 1 and 2 and allows a comparison between them. Shown are data from the first 10 (open symbols) and last 10 (filled symbols) sessions of each of the percentage reinforcement conditions. Pigeons 4505 and 9401 completed more chains per session under the signalled procedure at all percentages, and Pigeon 5982 completed more chains in the signalled 25% condition than in the unsignalled 25% condition. Two factors led to the large number of sessions employed in several of the phases. The first factor was the performance of Pigeon 5982, which tended to show considerable long-term "drift". The data from this pigeon often would show increasing or decreasing trends over 10 to 15 sessions, after which the trend would usually reverse. For example, in Figure 1 over the points from the last 10 sessions of the 75%-unsignalled condition (first determination) there is an upward trend, but the trend is within the range of variation obtained over the last 50 sessions of

Fig. 1. Number of chains completed in an approximately 1-hr session. Each set of coordinates is for a different pigeon. Y-axes: number of chains. X-axes: ordinal number of the session from the beginning of the experiments. The upper row of numbers on each X-axis shows session numbers for Experiment 1, the lower row shows session numbers for Experiment 2. Open symbols are data from the first 10 sessions of a condition, filled symbols are data from the last 10 sessions of a condition. Circles are data from Experiment 1 when outcomes were not signalled, squares are data from Experiment 2 when outcomes were signalled. The vertical lines denote a change of procedure and the percentage in boxes denote the programmed percentage of chains scheduled to end with food presentation.

Table 1
Mean Data from Last Five Sessions of Each Condition of Experiments 1 and 2

Pigeon	Nominal Percentage	Signalled?	Pause (sec)		Rate (R/sec)		% Reinf.	Sessions
			Postfood	Posttimeout	FI	EXT		
4505	100	No	11.91	—	3.38	—	100.0	36
	75	No	11.09	10.35	3.49	—	73.2	80
	50	No	13.04	11.84	2.29	—	50.6	63
	25	No	13.12	70.46	1.83	—	26.0	65
	75	No	11.35	7.50	1.12	—	72.8	82
	75	Yes	10.01	2.71	1.44	0.06	74.4	50
	50	Yes	7.17	0.60	2.38	0.06	48.1	47
	25	Yes	1.33	0.32	3.56	0.11	28.1	73
5982	100	No	12.94	—	0.86	—	100.0	36
	75	No	12.98	7.02	0.63	—	72.8	80
	50	No	20.07	15.20	1.62	—	53.7	63
	25	No	—	673.80	1.18	—	—	65
	75	No	25.36	28.64	0.52	—	72.8	82
	75	Yes	9.50	4.81	0.55	0.04	75.2	50
	50	Yes	8.08	26.49	0.75	0.04	48.3	29
	25	Yes	4.32	24.03	1.12	0.04	25.1	59
9401	100	No	12.33	—	0.94	—	100.0	36
	75	No	19.35	12.14	0.84	—	73.6	80
	50	No	19.69	15.31	0.92	—	51.9	63
	25	No	271.34	216.37	1.24	—	17.0	65
	75	No	28.58	21.51	0.86	—	75.0	82
	75	Yes	12.20	5.08	1.03	0.03	74.9	50
	50	Yes	8.35	1.17	0.88	0.02	52.0	47
	25	Yes	7.14	3.04	0.75	0.02	26.4	73

the condition. The second factor was that some of the changes observed were very slow to develop and become complete.

Table 1 shows that the response rate during the fixed-interval schedule did not change systematically across conditions, and that response rates were quite low during the 25-sec periods when the amber (pretimeout) stimulus was in effect. Also shown in the table are mean posttimeout and postfood pauses for all phases of the first two experiments. The pause at the beginning of the session was not included in determining these values. Generally, mean postfood pause was longer than mean posttimeout pause, with the differences being larger under the signalled conditions (Experiment 2). The difference was reversed in a few conditions where overall output was low, *i.e.*, below about 60 chains per session. Also, mean pause after food presentation decreased as the proportion of intervals ending with food presentation decreased during Experiment 2.

Figure 2 shows cumulative response records. Displayed for each pigeon are records from the simple chained FR 15 FI 25-sec condition, from the condition where 25% of the chains

ended with food presentation (Experiment 1), and from the condition where 25% of the sequences resulted in food presentation and the outcome was signalled (Experiment 2). The records are from the last or second-to-last session of a condition. The performance of Pigeons 4505 and 5982 on the red key (FR stimulus) consisted of a period of not pecking the key, followed by an abrupt transition to a high, constant rate until the FR was completed. Under the unsignalled conditions, Pigeon 9401 emitted pecks irregularly once it began responding under the FR schedule. Under the signalled conditions, Pigeon 9401's performance under the fixed-ratio schedule was similar to that of the other two pigeons. Performance in the presence of the green light (FI stimulus) was usually characterized by a few responses at the beginning of the 25-sec period, an indication that the pigeons usually "ran through" the transition from red to green, followed by a period of not pecking that was, in turn, followed by pecking at a high rate until food was delivered.

The decision to use chains completed per session as the main dependent variable, rather

Fig. 2. Three cumulative response records from each of the three pigeons in Experiments 1 and 2. Y-axis: cumulative key pecks. X-axis: time. The top two records for each pigeon are from Experiment 1, the bottom record is from Experiment 2. The pen reset to the baseline at the end of each chain and the recorder did not operate during either food presentation or time-outs. Marks on the event line indicate food presentations. The records are from the last or second-to-last session of a condition. Diagonal marks indicate completion of the FR; the short vertical lines at the left of each record mark the beginning of the session.

than some other measure such as key pecks per minute, was occasioned by the unitary nature of the performance under the chained schedule. The cumulative response records of Figure 2 illustrate the coherence of performance engendered by the chained schedule. In the middle record for each subject (*i.e.*, from the 25%-unsignalled condition), the overall rate indicated is quite low, yet when a chain was initiated it was invariably completed as a unit. Even when overall rates were low, key-

Fig. 3. Mean pause at the beginning of the FR in seconds as a function of percentage reinforcement, and mean running rate in response per second (running rate was defined as the rate of responses during completion of the FR 15 schedule) as a function of percentage reinforcement. There are two sets of coordinates for each pigeon. Squares display data from Experiment 1 in which outcomes were not signalled, circles display data from Experiment 2 when outcomes were signalled. Each point represents the mean from the last five sessions of a condition and the vertical bars on the points show the range of values over the last five sessions. The unconnected points are data from the second determination of the effects of 75% reinforcement in Experiment 1. Note that the Y-axes for mean prechain pause are logarithmic.

pecking rates during the fixed-ratio component of the chained schedule were high and constant.

Changes in the overall number of chains completed per session could have been due either to changes in the length of the pause at the beginning of the chain or to the rate of

pecking under the fixed-ratio schedule. Figure 3 illustrates that changes in both of these variables were correlated with changes in overall output. Under the signalled conditions, the mean pause preceding a chain (prechain pause) was shorter and the rate under the fixed ratio was higher than under corresponding unsignalled conditions. The pause at the beginning of a session was not included in the analysis. The differences in mean prechain pause between signalled and unsignalled conditions were accentuated as the percentage of sequences followed by food was decreased. Across subjects, there were no general systematic relationships between either mean prechain pause and percentage or mean rate under the fixed-ratio schedule and percentage. Computation of fixed-ratio rate did not include the pause at the beginning of the ratio.

Experiment 3

Figure 4 summarizes the main results of Experiment 3, in which timeouts were presented

Fig. 4. Chains completed per session over sessions of Experiment 3. The first 10 sessions shown are the last 10 sessions of Experiment 2. The center panel shows data from an unsignalled procedure, and the other two panels show data from a signalled procedure. The circles are data from Pigeon 4505, triangles show data from Pigeon 5982, and squares show data from Pigeon 9401. Twenty-five per cent of the chains were scheduled to end with food presentation.

independently of responding. Data in the left-hand portion of the figure are from the last 10 sessions of Experiment 2. When Experiment 3 began and the outcome of the chain was no longer signalled, all three pigeons completed fewer chains per session, and the reduction was apparent by the second session. Over the 17 sessions of this procedure, there was no indication that overall output was starting to increase after the initial decrease. Return to the conditions that prevailed at the end of Experiment 2 resulted in an increase in the number of chains completed per session; this effect also appeared within two sessions of the change in procedure. Table 2 presents quantitative data from Experiment 3 that indicate that the low overall output of key pecks during the unsignalled phase, as compared to the signalled phase, was correlated with both an increase in the mean length of the pause at the beginning of the fixed ratio and a decrease in the rate of responding during the fixed ratio. When overall output of Pigeons 5982 and 9401 was relatively low, *i.e.*, less than about 70 chains per session, the mean pause after timeout was longer than the mean pause after food.

Experiment 4

In Experiment 4, both timeouts and food were presented independently of responding. Quantitative data are presented in Table 2. In the first phase of the experiment (50%-signalled), responding was well maintained. Response rates during the fixed ratio were high and the mean pause after food delivery was longer than the mean pause after timeouts. The three pigeons, however, developed different patterns of responding during the FT component of the chain, as shown in the cumulative response records of Figure 5. The records are segments from the last session of the phase. Pigeons 4505 and 5982 both pecked at moderate rates during the FT components. Pigeon 4505, however, tended to slow down as the interval progressed, whereas Pigeon 5982 usually pecked the key more frequently near the end of the fixed-time period. Pigeon 9401's rate during the FT was much lower than the rates of the other two pigeons, but was nevertheless slightly higher than its rate during the pretimeout periods (*cf.* Table 2). At the beginning of the first session of the procedure none of the pigeons pecked the white key (FT stim-

Table 2
Mean Data from the Last Five Sessions of Each Condition of Experiments 3 and 4

Pigeon	Exp.	% Reinf.	Signalled?	Pause (sec)		Rate (R/sec)			Chains Completed	Sessions
				Postfood	Posttimeout	FR*	FI or FT	EXT		
4505	3	26.4	No	24.77	37.68	2.90	1.99	1.98	54	17
	3	25.6	Yes	1.57	0.52	8.66	3.85	0.13	116	10
	4	48.8	Yes	6.59	0.63	5.67	1.15	0.05	103	39
	4	25.9	Yes	1.90	0.80	5.56	0.96	0.11	112	106
	4	21.3	No	27.87	39.39	3.44	0.92	0.97	51	43
	4	24.2	Yes	1.70	1.03	6.01	1.24	0.10	109	17
5982	3	26.6	No	38.57	156.31	3.68	1.15	0.96	27	17
	3	24.4	Yes	6.01	30.73	5.04	0.88	0.04	81	10
	4	54.0	Yes	5.00	1.10	5.05	0.66	0.03	103	39
	4	23.2	Yes	10.34	130.77	3.67	1.02	0.03	33	106
	4	18.2	No	69.75	585.16	2.18	1.07	1.14	6	43
	4	24.3	Yes	19.89	99.33	3.52	0.97	0.03	34	17
9401	3	20.4	No	36.85	45.45	1.20	1.28	0.92	45	17
	3	26.6	Yes	8.33	3.24	3.71	0.03	0.01	96	10
	4	50.9	Yes	11.14	5.36	3.81	0.10	0.03	88	39
	4	26.2	Yes	9.43	4.51	4.55	0.10	0.02	95	106
	4	23.2	No	29.68	28.78	1.19	0.19	0.13	51	43
	4	22.2	Yes	9.30	2.35	4.27	0.12	0.02	100	17

*Calculation of FR rates did not include the pause at the beginning of the ratio.

Fig. 5. Segments of cumulative response records from the last session of the first condition of Experiment 4. Y-axis: cumulative pecks. X-axis: time. The recorder reset to baseline at the end of each chain and did not operate during food presentation or timeout. Marks on the event line indicate food presentations. Fifty per cent of the chains were scheduled to end with food presentation. Diagonal marks indicate completion of the FR.

ulus), but by the end of that session, patterns similar to those shown in Figure 5 had developed.

The effects of switching to an unsignalled procedure (*i.e.*, only white presented in the second component) with 25% of the sequences ending in food presentation are shown in Figure 6. There was a sharp drop in overall output for all three pigeons within a few sessions of exposure to the unsignalled procedure. The number of chains completed per session continued to decline for Pigeon 5982 over the course of the condition. Data in Table 2 show that the reduction in the number of sequences was again correlated with an increase in the mean length of the pause at the beginning of sequences and with a decrease in mean key-pecking rate during the FR component. As in the earlier experiments, the integrity of the chain as a unit was not altered by changing to the unsignalled procedure. Re-instatement of the signalled condition resulted in a rapid return to high rates of responding for Pigeons 4505 and 9401, and also produced an increase in rate for Pigeon 5982.

DISCUSSION

These data show clearly that signalling the outcome of the chained schedule employed here maintained more key pecking than com-

Fig. 6. Number of chains completed per session over sessions in Experiment 4 for each of the three pigeons. All data shown were collected when 25% of the chains were scheduled to be followed by food presentation. The session numbers on the X-axis denote the number of sessions of exposure to the conditions where 25% of the chains terminated with food presentation in Experiment 4. The center panels show data from the procedure in which outcomes were not signalled; the other panels show data from a signalled condition.

parable conditions in which the outcome was not signalled. In Figure 1, there is a clear difference at the end of each phase between the total number of chains completed under the signalled and unsignalled conditions (except for the 50% condition for Pigeon 5982 as explained earlier); Figures 4 and 6 also demonstrate that, under conditions where 25% of the chains ended with food presentation, signalling the outcome resulted in more key pecking than that observed under conditions where the outcome was not signalled.

Experiments 3 and 4 were designed to examine two possible explanations of the dif-

ferences in key pecking observed between Experiments 1 and 2. In Experiment 1, key pecks produced timeouts; in Experiment 2, timeouts were presented independently of responding. It is well documented that response-dependent presentation of timeouts can, in some circumstances, function as punishment (Kaufman and Baron, 1968; McMillan, 1967). One possible interpretation, then, of the differences in behavior between Experiments 1 and 2 is that in Experiment 1, completion of the chain was occasionally punished, whereas in Experiment 2 it was not. In Experiments 3 and 4, however, timeouts were presented independently of responding in both signalled and unsignalled conditions, and the signalled procedures still resulted in more key pecking. A second possible explanation of the differences in performance in Experiments 1 and 2 is that in Experiment 1, the pigeons made more pecks per food presentation than in Experiment 2. Fantino (1968) and Moore and Fantino (1975) have shown that in choice situations, preferences were directed away from conditions in which relatively high rates, and therefore more responses per food presentation, were emitted. Experiment 4 was conducted to examine the possibility that this factor (*i.e.*, the differences in numbers of pecks per food presentation) was important in producing the differences in performance observed between Experiments 1 and 2. By arranging that all terminal events were presented independently of responding, the requirement of more responses in the unsignalled condition was eliminated. The procedure failed, however, to eliminate responding in the second component of the chained schedule. Pigeons 4505 and 5982 still emitted many more pecks per food presentation under unsignalled conditions than under the signalled procedure. Pigeon 9401, however, exhibited approximately equal rates of pecking in the second component in both signalled and unsignalled conditions. The difference between the effects of signalling and not signalling the outcome of the chain was, nevertheless, quite evident in the performance of Pigeon 9401 in Experiment 4, thus reducing the likelihood that the differences in key pecking between the signalled and unsignalled procedures were due to differences in the total number of pecks per food presentation. A better test, however, would be provided by cir-

cumstances under which pecks are prevented during the second component.

The present results are also in accord with the findings of other experiments involving intermittent reinforcement of performance under schedules. Earlier investigations of intermittent reinforcement of performance under chained schedules have shown that characteristic temporal patterns of responding are maintained under chained schedules when reinforcement is intermittent (Findley, 1962; Marr, 1969). In the present experiments, the unitary nature of the performance under the chained schedule was maintained under all procedures, in spite of the fact that the total number of chains completed per session ranged from one to 116. These data, then, supplement the findings of other investigators who have reported that characteristic performances are maintained in procedures where performance under simple schedules of reinforcement is intermittently followed by food presentation (e.g., Davenport and Thompson, 1965; McMillan, 1971; Neuringer and Chung, 1967; Zeiler, 1972).

The procedures in which outcomes were signalled are formally similar to the standard "observing-response" procedure (e.g., Branch, 1973; Kelleher, Riddle, and Cook, 1962; Wyckoff, 1952). Observing-response procedures for pigeons generally employ two keys. Responses on one key (main key) occasionally result in food presentation, whereas pecks on the other (observing key) occasionally result in the presentation of stimuli correlated with the contingencies in effect for responses on the first key, *i.e.*, change the schedule from mixed to multiple (Ferster and Skinner, 1957). The pattern of behavior that usually develops under such a procedure consists of fulfilling the response requirement on the observing key and then behaving in a manner appropriate to the discriminative stimuli that are presented as a result. These conditions are quite similar to those of the present experiments when the outcome was signalled. The major difference between the present procedures and the observing-response procedure is that here, the pigeons had to complete the fixed ratio in order for food presentation ever to occur; in an observing-response procedure, food presentation can occur in the absence of any pecking of the observing key.

The formal similarity between an observing-

response procedure and the present procedures is complemented by a functional similarity as well. As the overall frequency of food presentation was decreased in the present experiments in which outcomes were signalled, the rate of completing chains was not appreciably reduced. Branch (1973) reported that decreasing the frequency of food presentation in an observing-response procedure also did not result in any notable decrease in the rate at which fixed ratios on an observing key were emitted. Thus, in both the signalled procedures of Experiment 2 and in an observing-response paradigm, reducing the frequency of food presentation in the second component of a chain did not decrease rate of emission of behavior controlled by the first component. This result may be contrasted with the effects of reducing reinforcement frequency in the terminal component of standard chained schedules. The usual result of such a manipulation is that first-component rates are reduced as the frequency of food presentation is also reduced (Findley, 1962; Jwaideh, 1973), and in Experiment 1 decreasing the frequency of food presentation resulted in a decrease in overall rate in the fixed ratio. It appears, then, that the present signalled procedure might be considered as a one-key analogue of the more traditional observing-response procedure. The utility of one-key procedures that are functionally similar to two-key procedures has been demonstrated by the contribution of such procedures to the analysis of responding under concurrent interval schedules (*cf.*, e.g., Killeen, 1972; Shimp and Wheatley, 1971; Silberberg and Schrot, 1974; Todorov, 1972).

The present results are comparable to those from related chained-schedule and choice procedures, as well as observing-response procedures. They are consistent with data presented by Wilton and Clements (1971*b*), described earlier, in which key pecking was maintained at higher rates during the first component of a signalled chained schedule when only 20%, rather than 80%, of the chains ended with food presentation. The present data also supplement those of Wilton and Clements (1971*b*), in that a comparison between equivalent percentages of food presentation under signalled *versus* unsignalled conditions showed that the inverse relationship between rate during the first component of the chained schedule and percentage of food presentation was

due to pairing stimuli differentially with outcomes, rather than simply decreasing the frequency of food presentation.

My results are also consistent with those from both explicit and implicit choice procedures, in that they may be accounted for in terms of conditioned reinforcement (*cf.* Fantino, (*in press*); Kelleher and Gollub, 1962). Observing-response procedures are "implicit" choice procedures (*cf.* Kelleher *et al.*, 1962), in that the subject may respond under either a mixed or multiple schedule. Most subjects make observing responses and thus exhibit choice of the multiple schedule. In addition, several experiments employing variations of the concurrent chains procedure (*cf.* Autor, 1969) for determining choice have shown that pigeons' choices are directed towards multiple, rather than mixed schedules (Bower, McLean, and Meacham, 1966; Catania, 1975; Hursh and Fantino, 1974). These findings from observing-response and choice procedures can be accounted for by Wyckoff's (1959) proposal that the conditioned reinforcing potency of a stimulus is related in a positively accelerated fashion to the frequency of primary reinforcement in the presence of that stimulus. Simply stated, Wyckoff's hypothesis is that the average of the conditioned reinforcing potency of a stimulus consistently paired with food presentation and of a stimulus never paired with food presentation is greater than the potency of a stimulus that is intermittently paired with food presentation. This hypothesis, however, does not account for the results of experiments by Kendall (1974), nor for some aspects of the present results. Kendall's pigeons could gain access to conditions where food was presented on 50% of the occasions and was also signalled, or to conditions where food was presented on 100% of the occasions, always preceded by the same stimulus. Kendall reported that a preference was established for the condition in which a stimulus was differentially correlated with food presentation *versus* the condition in which a single stimulus always preceded food presentation, in spite of the fact that such a preference reduced the overall frequency of food presentation. Similarly, in the present experiments, rates of responding during the fixed-ratio first component were higher under conditions where the green key of the second component was differentially paired with food presentation (signalled percentage reinforcement)

ment) than when the green key always ended with food presentation (100% condition of Experiment 1). Both my results and those of Kendall (1974) suggest that provision of a contrasting stimulus that predicts the absence of food will increase the conditioned reinforcing potency of a stimulus that reliably precedes the delivery of food.

REFERENCES

- Allen, J. D., Porter, J. H., and Arazie, R. Schedule-induced drinking as a function of percentage reinforcement. *Journal of the Experimental Analysis of Behavior*, 1975, **23**, 223-232.
- Autor, S. M. The strength of conditioned reinforcers as a function of frequency and probability of reinforcement. In D. P. Hendry (Ed.), *Conditioned reinforcement*. Homewood, Illinois: The Dorsey Press, 1969. Pp. 127-162.
- Bower, G. H., McLean, J., and Meacham, J. The value of knowing when reinforcement is due. *Journal of Comparative and Physiological Psychology*, 1966, **62**, 184-192.
- Branch, M. N. Observing responses in pigeons: effects of schedule-component duration and schedule value. *Journal of the Experimental Analysis of Behavior*, 1973, **20**, 417-428.
- Catania, A. C. Freedom and knowledge: an experimental analysis of preference in pigeons. *Journal of the Experimental Analysis of Behavior*, 1975, **24**, 89-106.
- Davenport, J. W. and Thompson, C. I. The Amsel frustration effect in monkeys. *Psychonomic Science*, 1965, **3**, 481-482.
- de Lorge, J. Fixed-interval behavior maintained by conditioned reinforcement. *Journal of the Experimental Analysis of Behavior*, 1967, **10**, 271-276.
- Fantino, E. Conditioned reinforcement II: choice and information. In W. K. Honig, and J. E. R. Staddon (Eds.), *Handbook of operant psychology*. Englewood Cliffs, New Jersey: Prentice Hall, (*in press*).
- Fantino, E. Effects of required rates of responding upon choice. *Journal of the Experimental Analysis of Behavior*, 1968, **11**, 15-22.
- Ferster, C. B. and Skinner, B. F. *Schedules of reinforcement*. New York: Appleton-Century-Crofts, 1957.
- Findley, J. D. An experimental outline for building and exploring multi-operant behavior repertoires. *Journal of the Experimental Analysis of Behavior*, 1962, **5**, 125-166.
- Hursh, S. R. and Fantino, E. An appraisal of preference for multiple *versus* mixed schedules. *Journal of the Experimental Analysis of Behavior*, 1974, **22**, 31-38.
- Jwaideh, A. R. Responding under chained and tandem fixed-ratio schedules. *Journal of the Experimental Analysis of Behavior*, 1973, **19**, 259-267.
- Kaufman, A. and Baron, A. Suppression of behavior by timeout punishment when suppression results in loss of positive reinforcement. *Journal of the Experimental Analysis of Behavior*, 1968, **11**, 595-607.
- Kelleher, R. T. Chaining and conditioned reinforcement in W. K. Honig (Ed.), *Operant behavior: areas*.

- of research and application. New York: Appleton-Century-Crofts, 1966. Pp. 160-212.
- Kelleher, R. T. and Gollub, L. R. A review of positive conditioned reinforcement. *Journal of the Experimental Analysis of Behavior*, 1962, 5, 543-597.
- Kelleher, R. T., Riddle, W. C., and Cook, L. Observing responses in pigeons. *Journal of the Experimental Analysis of Behavior*, 1962, 5, 3-13.
- Kendall, S. B. Preference for intermittent reinforcement. *Journal of the Experimental Analysis of Behavior*, 1974, 21, 463-473.
- Killeen, P. A. A yoked-chamber comparison of concurrent and multiple schedules. *Journal of the Experimental Analysis of Behavior*, 1972, 18, 13-22.
- Marr, M. J. Second-order schedules. In D. P. Hendry (Ed.), *Conditioned reinforcement*. Homewood, Illinois: The Dorsey Press, 1969. Pp. 37-60.
- McMillan, D. E. A comparison of the punishing effects of response-produced shock and response-produced time out. *Journal of the Experimental Analysis of Behavior*, 1967, 10, 439-449.
- McMillan, J. C. Percentage reinforcement of fixed-ratio and variable-interval performances. *Journal of the Experimental Analysis of Behavior*, 1971, 15, 297-302.
- Moore, J. and Fantino, E. Choice and response contingencies. *Journal of the Experimental Analysis of Behavior*, 1975, 23, 339-347.
- Neuringer, A. J. and Chung, S.-H. Quasi-reinforcement: control of responding by a percentage-reinforcement schedule. *Journal of the Experimental Analysis of Behavior*, 1967, 10, 45-54.
- Shimp, C. P. and Wheatley, K. L. Matching to relative reinforcement frequency in multiple schedules with a short component duration. *Journal of the Experimental Analysis of Behavior*, 1971, 15, 205-210.
- Silberberg, A. and Schrot, J. A yoked-chamber comparison of concurrent and multiple schedules: the relationship between component duration and responding. *Journal of the Experimental Analysis of Behavior*, 1974, 22, 21-30.
- Staddon, J. E. R. and Innis, N. K. Reinforcement omission on fixed-interval schedules. *Journal of the Experimental Analysis of Behavior*, 1969, 12, 689-700.
- Todorov, J. C. Component duration and relative response rates in multiple schedules. *Journal of the Experimental Analysis of Behavior*, 1972, 17, 45-49.
- Wilton, R. N. and Clements, R. O. Observing responses and informative stimuli. *Journal of the Experimental Analysis of Behavior*, 1971, 15, 199-204. (a)
- Wilton, R. N. and Clements, R. O. The role of information in the emission of observing responses: a test of two hypotheses. *Journal of the Experimental Analysis of Behavior*, 1971, 16, 161-166. (b)
- Wyckoff, L. B. Toward a quantitative theory of secondary reinforcement. *Psychological Review*, 1959, 66, 68-78.
- Wyckoff, L. B. The role of observing responses in discrimination learning: Part I. *Psychological Review*, 1952, 59, 431-442.
- Zeiler, M. D. Fixed-interval behavior: effects of percentage reinforcement. *Journal of the Experimental Analysis of Behavior*, 1972, 17, 177-189.
- Zimmerman, D. W. Intermittent reinforcement of discriminatively controlled responses and runs of responses. *Journal of the Experimental Analysis of Behavior*, 1960, 3, 83-91.
- Zimmerman, D. W. Rate changes after unscheduled omission and presentation of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1971, 15, 261-270.

Received 19 February 1976.

(Final Acceptance 2 August 1976.)