REVERSAL OF PREFERENCE UNDER PROGRESSIVE-RATIO SCHEDULES BY PUNISHMENT¹

J. F. DARDANO

UNIVERSITY OF MARYLAND

A progressive-ratio reinforcement schedule, in which successive reinforcements required an additional 50 responses, was programmed on one key. A response on a second key reset the progressive-ratio schedule to the first step. Before punishment, all pigeons consistently reset the schedule after reinforcement on the first step, thereby minimizing the number of responses required for reinforcement. Punishment was a brief electric shock contingent upon each response on the reset key. The first effect of punishment was to change the frequency of extra responses on the reset key. Under higher intensities of punishment, the pigeons completed the advanced steps of the progressive-ratio schedule before resetting to the first step. Completions of advanced steps were accompanied by decreases in the overall rate of responding and the rate of reinforcement. When the punishment contingency was removed, the major features of pre-punishment performance were recovered.

In accordance with the general view that organisms select the reinforced behavioral sequence involving the least effort, various studies have demonstrated that subjects exposed to different fixed-ratio (FR) reinforcement schedules, in which reinforcement is contingent upon completing a constant number of responses, prefer the schedule with the lowest response requirement. The general methodology of these investigations was to program different FR schedules on one response key and correlate the presence of each schedule with a distinctive stimulus. The subjects could switch the schedule by responding on a second response key. Verhave (1963) showed that pigeons preferred the shorter of two FR schedules and determined the "equivalence value" of the schedules by raising the response requirement on the switching key. Humans also exhibited marked preferences for the shorter FR schedule (Weiner, 1965). Rather than comparing two different FR schedules, Findley (1958), working with pigeons, programmed the primary reinforcer on a progressive-ratio (PR)

schedule, in which the number of responses required for successive reinforcements increased by a given increment. The pigeons consistently recycled the PR to the first step by responding on the switching key, thereby programming the minimum response requirement for reinforcement. Herrnstein (1958), using another procedure in which two FR schedules with different values were concurrently programmed on two continuously accessible keys, found that responding was more frequent on the key associated with the lower FR values when the two ratio sizes differed by a large amount. The preference for shorter ratios, reported by these studies, was at least partly based on the rate of reinforcement, which is always confounded with different ratio sizes. The lower rate of reinforcement under longer FR schedules is a direct result of the proportional relationship between the duration of the postreinforcement pauses and the size of the ratio as well as the additional time required to execute more responses.

Recent studies have discovered another factor underlying the preference for the shorter ratio requirement. Stimuli associated with responding under a FR schedule may acquire aversive properties, and the strength of the aversiveness is proportional to the size of the ratio. This property of FR schedules was demonstrated by providing subjects with a second

¹This research was supported by Grant No. NsG 189-61 from the National Aeronautics and Space Agency. The technical assistance of E. Taylor is acknowledged. Reprints may be obtained from the author, Space Research Laboratory, Heavy Research Building, Unit B, University of Maryland, College Park, Maryland 20742.

key, a response on which removed all stimuli associated with the presence of the FR schedule. Azrin (1963) permitted pigeons to initiate and terminate a timeout period from the FR schedule. The frequency and duration of these self-imposed extinction periods were proportional to the size of the FR. A similar result was found with rats (Thompson, 1964). Appel (1963) confirmed the relationship between frequency, but not duration, of timeout periods and size of the ratio. Zimmerman and Ferster (1964) suggested other variables which might control switching in this situation, such as degree of stimulus change between timeout and reinforcement conditions, and the degree of control by the subject over removal of the timeout condition. If the stimuli associated with FR reinforcement schedules are aversive, they might be capable of acting as punishers. This effect was shown by Thompson (1965) who found that a stimulus correlated with the presence of high FR schedules suppressed responding under another reinforcement schedule.

The preference for a shorter work requirement, based on reinforcement rate and possible schedule aversiveness, raises the question of procedures which could be employed to maintain responding under the longer ratios. One method of changing the preference for the shorter response requirement involves punishment of the responses under the shorter FR. Since escape from punishment is capable of maintaining a large output of responses (Azrin, Hake, Holz, and Hutchinson, 1965), responding under the longer non-punished ratio would be reinforced by escape from punishment in addition to the primary positive reinforcer. Using Findley's procedure of permitting the subject to recycle a PR schedule to the minimum step by responding on a second key, all food-key responses were punished under one of two key colors which alternated when the PR was recycled (Dardano and Sauerbrunn, 1964). This punishment contingency resulted in completion of advanced PR steps under the nonpunished color. The present study was concerned with another punishment condition as a means of generating responding under longer PR steps; *i.e.*, punishment of the response which recycles the PR to the minimum step. In this case, the subject is punished for producing the occasion for a shorter work requirement.

METHOD

Subjects

Three 5-yr-old male White Carneaux pigeons, experimentally naive, were maintained at 80% of their free-feeding weight throughout the study. They were housed in individual units with continuous access to grit and water.

Apparatus

Two similar experimental chambers, each furnished with an air blower, a speaker for masking noise, a relay for response feedback, and a grain feeder, were used. Two response keys, 5 cm apart, were located on the front panel. One key was transilluminated by a white lamp, the second, by a red or a green lamp. The houselights were two white lamps at the top rear of the chamber. All lights were 6 w. The experimental chamber was set within a larger enclosure to attenuate external stimuli.

The punishing stimulus was a pulse of 60 Hz ac controlled by a circuit consisting of an auto-transformer, step-up transformer, milliammeter or voltmeter, and a series resistor of at least 10 K ohms. A relay closure placed the subject in series with the circuit. The shock was delivered through silver electrodes around each pubis bone via a swivel mounted on the roof of the chamber (Azrin, 1959). Shock durations were 150 msec for B-24 and 50 msec for B-33 and B-58. Shock intensities were determined by shorting the shocker output and setting the desired intensity on the milliammeter in the shocker used for B-24 and B-33 or on the voltmeter in the shocker for B-58. The electrical impedance of a subject was measured with a bridge circuit using a 7-v 60-Hz input. The average electrical impedances were 1800 ohms for B-24, 1700 ohms for B-33, and 1260 ohms for B-58.

Procedure

The progressive-ratio, positive-reinforcement schedule consisted of an initial ratio of 50 and an increment of 50 in the size of each subsequent ratio. Responses on the right key, designated the food key, were reinforced with 3-sec exposure to mixed grain in accordance with the requirements of the PR schedule; *i.e.*, the first reinforcement on the fiftieth response, the second reinforcement on the one-hundredth response, the third on the one hundred

fiftieth response, *etc.* The color of the food key remained either red or green until the PR schedule was recycled to the first step, then the color changed to the second of the two possible. A single response on the left key, designated the reset key, recycled the PR to the first step and changed the food-key color any time after the first PR step of 50 had been completed. If the subject responded on the reset key before completing the first PR step, the count would revert to zero and the food-key color would not change. Therefore, reinforcement always required 50 consecutive responses on the food key after a response on the reset key. Additional responses on the reset key before responding on the food key were inconsequential. The white reset key was illuminated continuously except during the magazine cycle when the key lights and the house light were extinguished. The maximum number of times the PR could be reset in a session was one less than the number of reinforcements programmed for the session. Under the PR schedule with the reset option, the subjects could program reinforcements on the minimum ratio of 50 by responding on the reset key each time the first PR step was completed.

Preliminary training included a minimum of 20 sessions on FR 50 with the reset key covered and the color of the food key changing after each reinforcement. After a stable FR performance had developed, at least 2500 re-

inforcements were programmed under the PR schedule with the reset key operative. After 10 consecutive sessions in which the behavior appeared stable in terms of the number of resets of the PR, overall response rate on the food key, and total responses on the reset key, the punishment contingency was introduced. This consisted of the delivery of electric shock contingent on each peck on the reset key. All responses on the reset key were punished; responses on the food key never were. The shock intensity was initially 2 ma and was increased by steps of 1 or 2 ma. Each shock level was programmed for a minimum of six sessions, and the intensity was increased after the aforementioned behavioral properties appeared stable over five consecutive sessions. When the shock intensity was sufficient to suppress responses on the reset key completely for five consecutive sessions, which defined the maximum shock intensity for each subject, the punishment contingency was removed for a minimum of 20 sessions. The experimental procedure is summarized in Table 1. The shock intensities for B-58, programmed in volts, are expressed in milliamperes. In the remainder of the report, a given shock intensity for a subject is presented as the absolute value in milliamperes and also as the percent of the maximum intensity for the subject. The percentile value is listed in parentheses after the milliamperage. There were two additions to the procedure. The maximum intensity avail-

Table 1

The number of sessions and reinforcements under each shock level for each subject. The left column of shock levels refer to B-24 and B-33; the right column, to B-58. Shock intensities are in milliamperes and are listed in order of presentation.

Shock Intensity (ma)	B-24		B-33		Intensity (ma)	B-58	
	Sessions	Reinf.	Sessions	Reinf.		Sessions	Reinf.
0	69	2530	74	2700	0	57	2990
2	17	595	33	1155	1.4	9	540
4	23	805	17	595	3.0	11	660
5	—	—	11	385	4.6	16	960
6	23	805	30	897	6.2	11	660
7	—	—	20	170	7.8	34	941
8	19	665	14	46	9.4	15	276
10	18	601	—	—	11.0	25	235
12	21	641	—	—	12.6	25	161
13	18	360	—	—	0	50	2491
14	13	200	—	—			
15	10	85	—	—			
16	37	320	—	—			
0	20	562	20	572			

able from the shocker, 18 ma, did not suppress the reset responses of B-24 with a shock duration of 50 msec, so the entire punishment sequence was repeated on this subject with a shock duration of 150 msec. The performances under the shorter shock duration by B-24 are not included in the analyses. Also, B-33 was exposed again to all punishment intensities to determine performance reliability. The behavioral effects under the various shock levels were replicated. The analysis is based on the first set of data for B-33.

Each experimental session was terminated after all programmed reinforcements were delivered, 60 for B-58 and 35 for both B-24 and B-33, or after 1 hr, whichever occurred first. The number of reinforcements programmed for each subject approximately maintained its experimental weight. The weights and the electrical resistances of the birds were measured before and after each session. Experimental weights were maintained by post-session feeding. Data were recorded with counters, running-time meters, and a cumulative recorder. The programming and recording equipment were located outside of the room housing the experimental chambers.

RESULTS

Data are presented for the final performances under the experimental conditions. The transition performances are not described. When an average value is used, it is the arithmetic mean of the values for the final five sessions under the experimental condition.

Pre-punishment Performance and Initial Effect of Punishment

The final performances of all subjects before punishment was introduced were extremely efficient in terms of programming the minimum number of 50 responses for reinforcement by responding on the reset key after completing the first step of the PR schedule. If the PR was always recycled after reinforcement on the first step, the average number of responses per reinforcement would be 50. These averages were 58 for B-24 and B-33 and 54 for B-58. Over the last five sessions, the proportions of the PR resets, after the first PR step was completed, relative to the maximum number of resets possible were 0.89 for B-24, 0.85 for B-33, and 0.94 for B-58. The responses

on the reset key were limited to the interval after reinforcement and before responding on the food key. The subjects would pause after reinforcement, then emit the reset response and immediately start the first step of the PR on the food key. After the reset response recycled the PR, the pigeons would occasionally peck this key once or twice before responding on the food key. The average numbers of these superfluous responses on the reset key in a session were 7 for B-24, 12 for B-33, and 38 for B-58. The average response rates on the food key were approximately 160 responses per min for B-33 and B-58 and 218 responses per min for B-24. Figure 1 shows cumulative response records of the pre-shock performances of each subject.

Under low shock intensities, only the frequency of superfluous responses on the reset key was consistently affected by the punishment contingency. The average number of these responses in a session by B-24 declined from the pre-shock value of 7 to 2, and by B-58, from 38 to 2. The frequencies continued to decrease at higher shock intensities. In the case of B-33, however, the frequency of superfluous reset-key responses initially increased from the preshock average of 12 to 25. Under the next higher shock intensity, the average frequency decreased to four, then to zero at still higher shock levels. The increase in the frequency of these superfluous responses, which was specific to a given shock level before their decrease, recurred when B-33 was again exposed to the entire sequence of shock intensities. The phenomenon will be discussed later.

Under the low shock levels which produced these changes in frequency of superfluous reset-key responses, other performance aspects did not show any consistent change. The overall response rates of B-33 and B-58 on the food key remained at the preshock levels, approximately 160 responses per min, and the rate of B-24 declined slightly to 191 responses per min. Only B-24 responded through the fourth PR step of 200, which none of the subjects had completed during the preshock performance.

Performances under Higher Shock Intensities

Under a higher shock intensity, each subject started responding through the longer steps of

Fig. 1. Cumulative response records illustrating the performances of each subject before the punishment contingency. The second record by B-24 is a later performance under a shock intensity of 8 ma (50%). Each record is a complete session. Pips of the response pen denote reinforcements at the completion of a PR step. Deflections of the event pen indicate responses on the reset key. The response pen returns to the baseline before the maximum excursion when a response on the reset key recycled the PR schedule to the first step.

the PR before resetting the schedule. All subjects frequently completed PR steps of 250 or higher; they were never completed under the lower shock levels. The cumulative records in Fig. 2 illustrate the first consistent preference for the longer PR steps by each subject. Although each of the performances was under a shock level at which the advanced PR steps were first consistently completed, the performances are not comparable because the aversiveness of the shock, in terms of the degree of suppression of reset-key responses, differed among the subjects.

The onset of responding under advanced steps of the PR schedule was accompanied by other performance changes. The frequency of superfluous responses on the reset key declined to four or less. Longer postreinforcement pauses and breaks in responding during a ratio resulted in lower overall rate. The response breaks usually occurred during the early part of the ratio. The presence of a strained ratio in the PR sequence was not a certain indication that the PR schedule would be reset when that step was completed. Often, the subjects completed the next step at a high,

Fig. 2. Sample cumulative response records of the performance of each subject under the first shock intensity which produced responding through the longer steps of the PR schedule. Each record is a complete session. Recording as in Fig. 1.

regular rate. When a reset response occurred after reinforcement, the delay preceding the reset response was quite variable. Occasionally, the subjects reset the PR schedule after an appreciable number of responses on a PR step.

Responding under higher PR steps was initiated abruptly for B-33 and B-58 when the shock intensities reached 6 ma (75%) and 7.8 ma (62%), respectively. In the case of B-24, the initial preference for longer PR steps under 10 ma (63%) was preceded by an intermediate type of performance at a lower shock level. As seen in the second cumulative record for B-24 in Fig. 1, the earlier performance was typified by frequent completions of the second PR step; this was probably due to the wider range of intensities available with this subject.

Following the shock intensity which initially produced a preference for longer PR

steps by each subject, further increments in the shock level increased the magnitude of performance changes. Longer PR steps were completed, postreinforcement pauses lengthened, response breaks during a ratio increased in frequency and duration, the overall response rate declined, and the PR was reset less frequently after the first or second step was completed. These effects of intense punishment are illustrated by the cumulative records in Fig. 3, which show the performances of B-24 and B-58 under a shock intensity which suppressed reset responses to approximately five per session. The inserts in Fig. 3 are segments from other sessions which illustrate another feature of the performances under intense punishment; namely, the occasional occurrence of an extended break in responding during the first ratio after the PR schedule was reset. Since the shock level which first produced respond-

Fig. 3. Sample cumulative records of the performance of B-24 and B-58 under a shock intensity which suppressed responding on the reset key to an average of four per session. The two upper records are complete sessions. The records at the bottom of the figure are excerpts from another session under this shock intensity. Recording as in Fig. 1.

ing into the higher PR steps by B-33 also suppressed responding to an average of six responses per session, the cumulative record for B-33 in Fig. 2 is comparable to those for the other subjects in Fig. 3.

Extremely intense punishment, which suppressed responding to the minimum of one per session, did not generate further responding into the PR schedule relative to the preceding shock level. The subjects did not consistently complete longer PR steps nor respond more frequently under advanced steps of the PR. The average number of responses per reinforcement increased for all subjects, but this was due primarily to the fewer number of resets after the early PR steps. As seen in the cumulative records in Fig. 4, the per-

formances were extremely strained under the highest shock level at which each subject still executed a reset response in the session. The durations of postreinforcement pauses, and the frequency and duration of breaks in responding during a ratio all increased. Consequently, for all subjects, the average response rates on the food key declined to less than 25 per min, and the average number of reinforcements in a session was less than 10. The subjects recycled the PR during the first half of the session and after completing approximately five PR steps. The reset response was not preceded by an extended pause. It was executed a few minutes after reinforcement or after responding was initiated on the next PR step. Extended pausing and response breaks

Fig. 4. Sample cumulative records of the performances of each subject under a shock level which suppressed resets of the PR schedule to an average of approximately one per session. Complete sessions are shown for B-33 and B-58. No responding by B-24 occurred in the part of the session which is not shown. Recording as in Fig. 1.

during the first ratio after the reset response, noted earlier under a high shock level, were more frequent. The number of PR steps completed before and after the reset response were approximately equal.

Suppression of Reset Responses and Recovery

As was the case when reset responses were minimal, the complete suppression of reset responses by the punishment contingency did not consistently result in completions of longer PR steps relative to the preceding shock level. The average number of responses per reinforcement did increase for B-24, but this was due to fewer completions of the ini-

tial PR steps. Although long periods without responding were common in the sessions, all subjects started responding without excessive delay, and often immediately, at the start of the session. The absence of extended delays before starting to respond in a session occurred under all shock levels. With complete suppression of reset responses, the response rates on the food key remained low, ranging from 6 to 19 responses per min, and the average number of reinforcements per session reached a minimum value of six for B-24, three for B-33, and five for B-58. Figure 5 shows a sample performance of each subject. The extended postreinforcement pausing and extended breaks during these sessions, when

Fig. 5. Sample cumulative records of the performances of each subject under a shock level which completely suppressed responses on the reset key. Parts of the session of B-24 and B-33 in which no responses occurred are deleted. The record of B-58 was telescoped. Recording as in Fig. 1.

the reset option was available but never executed, are characteristics of performance under PR schedules without a reset option (Hodos and Kalman, 1963).

Table 2 is a summary of data which indicate the extent of the excursions into the PR schedule under each shock level by each subject. A table entry is the number of times that a given PR step was completed and followed by a reset response or by the end of the session. For example, if the subject completed the first, second, and third PR step and then reset the PR, this would be included in the frequency under the 150 PR step for the particular shock level. Since only the longest completed step before reset in each excursion was counted, the frequencies of the higher PR steps can exceed those of the lower steps. Each entry is the total frequency during the last five sessions under a given shock level. The table provides data for some of the specific results noted earlier: the efficiency of each subject's preshock performance, the abrupt onset of responding through the higher PR steps by B-33 and B-58 at a particular shock level, the intermediate performance of B-24 before completing higher steps, and the decline in the frequency of completed

ratios as shock intensity increased. In addition to these aspects of performance, Table 2 illustrates the following general effect of the punishment contingency. Each subject completed the longer PR steps most frequently under a shock intensity lower than the maximum intensity for the subject, and further increases in the shock level did not consistently result in completion of still higher PR steps nor more frequent completions of advanced PR steps. For example, all subjects completed PR steps of 200 or higher most frequently when the shock level was 75% of maximum intensity. The major effect of further increases in shock intensity, aside from producing a more strained performance, was to reduce the frequency of resets after the lower steps of the PR schedule.

When the punishment contingency was removed, all subjects largely recovered their pre-shock performance within eight sessions after the first nonpunished response on the reset key. The major transitions during the recovery are shown in Fig. 6 for B-24, Fig. 7 for B-33, and Fig. 8 for B-58. The recovery performances of all subjects exhibited two common features. The first was the absence of

Fig. 6. Cumulative records showing the recovery of performance by B-24 after removal of the punishment contingency. Each record is a complete session. The circled number above each record is the number of the session. Numbering was started with the first session in which a response on the reset key occurred. Recording as in Fig. 1.

Table 2

The final ratio of the progressive ratio completed before resetting the progressive ratio. Table entries are frequencies of the last five sessions under each shock level. Numbers in parentheses beside each intensity express the milliamperage as the percent of the maximum intensity for the subject.

Subject	Shock Intensity in ma		Progressive Ratio Steps										
			50	100	150	200	250	300	350	400	450	500	550
B-24	0	(0)	137	19									
	2	(13)	147	14									
	4	(25)	145	12	2								
	6	(38)	131	12	4	2							
	8	(50)	81	36	6	1							
	10	(63)	42	24	10	6	3	1					
	12	(75)	29	15	7	6	7	1					
	13	(81)	12	6	3	4	2						
	14	(88)	2	3	2	4	4	1	1				
	15	(94)	1	1	2	3	3						
	16	(100)	0	0	0	2	1	2	0	1	0	1	
B-58	0	(0)	255	21	1								
	1.4	(11)	238	25	4								
	3.0	(24)	236	29	2								
	4.6	(37)	229	34	1								
	6.2	(49)	210	34	8								
	7.8	(62)	22	21	7	6	3	1	1				
	9.4	(75)	3	5	3	6	2	1	0	3			
	11.0	(87)	1	2	1	1	3	0	0	0	0	0	1
	12.6	(100)	1	2	1	1	0	0	3	1			
B-33	0	(0)	126	20	3								
	2	(25)	135	20									
	4	(50)	104	34	1								
	5	(63)	143	16									
	6	(75)	5	10	7	6	0	2	2	1			
	7	(88)	0	0	1	1	2	2	1				
	8	(100)	0	2	2	1							

frequent and effective resetting of the PR schedule after the initial few unpunished responses on the reset key. As seen in the figures, B-24 was still completing the 200-response step of the PR three sessions after the first unpunished response, B-59 continued to respond into advanced PR steps after two sessions, and B-33 stopped responding in the first session with the disruption still present in the third session. The second common feature was the high frequency of inconsequential responses on the reset key. These responses were emitted in bursts and sometimes alternated with responding on the food key. Notable examples can be seen in Session 8 for B-24, Sessions 1, 2, and 3 for B-33, and Sessions 3 and 4 for B-58. After 20 sessions without punishment, the performances differed from the prepunishment performances in the following respects: overall response rates of B-24 and B-58 were lower, B-24 and B-33 emitted more super-

fluous responses on the reset key, and B-58 less frequently reset the PR after the first step.

Figure 9 summarizes several of the results of the investigation. The three graphs for each subject present the following data as a function of punishment intensity: the overall rate on the food key, the average number of responses per reinforcement, and the number of times the PR schedule was reset, along with the total number of responses on the reset key. These functions show the following general relationships: (1) the reduction in the frequency of superfluous reset-key responses as the shock level increased with the exception of the temporary increase by B-33 at 63% maximum intensity, (2) the increase in the number of responses per reinforcement which reached a maximum of approximately 180, and (3) the reduction in response rate after the subjects started to complete the longer PR steps.

Fig. 7. Cumulative response records showing the recovery of performance by B-33 after the punishment contingency was removed. Each record is a complete session. The number of the session, starting with the first session with a reset response, is encircled in front of each record. Recording as in Fig. 1.

DISCUSSION

Punishing the operant which produced the lower response requirement for reinforcement effectively reversed the relative preference for the shorter ratio. The subjects selected the option of responding through the longer steps of the PR schedule rather than execute the punished reset response. The maximum PR step completed and the frequency of responding under the longer PR steps were related to punishment intensity. Within a limited range of punishment intensities, the subjects often completed longer PR steps and still maintained an appreciable rate of responding.

The temporary preference for either of the alternative behaviors under a given intensity of punishment can be analyzed in terms of the changing relationship between the fixed level of aversiveness of the punishing stimulus and

the strength of responding under the PR schedule. When the punisher was sufficiently aversive partially to suppress responses on the reset key, the subjects would select the previously non-preferred alternative of responding through a longer PR step. None of the properties associated with this alternative, which were responsible for its less-preferred status under lower punishment intensities, had changed; thus, the subject was confronted with less-favorable alternatives than were present at lower punishment levels. As successively longer steps of the PR were completed, the increasing number of responses required for primary positive reinforcement resulted in a decreasing tendency to continue responding under the PR schedule. Also, the aversive properties associated with responding under longer ratios increased. At some point in the PR schedule, continued responding through a longer step became less favorable than the alternative behavior of executing the punished reset response. After the reset response, the original relationship between the strengths of the two behaviors was reestablished, and the sequence of behavior would be repeated. With higher intensities of punishment scheduled on the reset key, less-favorable conditions for both operants were present, and periods without responding became more prominent. When the punishment intensity was sufficiently high to suppress responses on the reset key completely, responding through the longer PR steps could not attain the degree of aversiveness necessary to counteract the punishment, and responding in the situation depended upon the maximum number of responses which could be maintained by the PR reinforcement schedule. This description of some of the variables controlling the performance does not account for those instances when the subject reset the PR after completing the first or second step under high punishment intensities. These resets after abbreviated responding might represent a continued effect of earlier responding under very high PR steps.

The number of additional responses which can be generated by this procedure is determined by an inherent self-limiting property. Increases in punishment intensity drive the subject deeper into the PR, but continued responding in the PR in turn develops conditions which weaken and suppress the behav-

Fig. 8. Cumulative response records showing the recovery of performance by B-58. Complete sessions are shown. The number of the session, starting with the first session with a reset response, is circled above each record. Recording as in Fig. 1.

ior. The inverse relationship between the number of responses per reinforcement and the overall response rate reflects the self-limiting nature of these contingencies. Under the punishment intensity which generated the maximum number of responses per reinforcement, approximately 180, or more than three times the minimum ratio, the overall response rate declined to less than 30 responses per min. In addition to the extended periods without responding, the performance under intense punishment exhibited another feature indicating the strained nature of the behavior. On the infrequent occasions when the subject recycled the PR by executing the punished response on the reset key, there were occa-

sional long pauses before initiating the first step and breaks while responding during this ratio. These effects on responding with the minimum response requirement programmed might be due to the generalized suppressing effect of punishment from the reset key to the food key and/or the emotional reaction elicited by intense punishment interfering with the control of the primary positive reinforcer.

The frequency of superfluous responses on the reset key was the first aspect of performance affected by the punishment contingency. These responses were sensitive to punishment intensities which did not modify the overall response rate nor the extent of responding into the PR. The frequency of superfluous re-

Fig. 9. Summary of data for each subject. The following measures are plotted as a function of per cent of maximum shock intensity: the overall rate on the food key in responses per minute, the number of responses emitted per reinforcement, and the number of resets of the PR schedule along with frequency of reset-key responses. The shock intensities corresponding to the per cent values are presented in Table 2. Each column of three graphs presents data for one subject. The data points are the arithmetic means of the values for the final five sessions under a given shock intensity. In the graph showing frequency of reset responses, the open circles denote frequency of responses on the reset key, and the solid circles indicate the number of resets of the PR schedule. The last point in each graph, not connected to the preceding point, refers to the postshock performance.

sponses regularly declined from the preshock frequencies for two subjects, but the frequency of such superfluous responses by B-33 increased before decreasing at the next higher shock intensity. The same phenomenon recurred when B-33 was reexposed to the sequence of punishment intensities. Another pigeon used in some preliminary work also showed this effect; responses on the reset key increased more than twofold under a punishment level which did not appreciably affect other properties of the performance. This apparently contradictory reaction by B-33 can be interpreted as an instance of pain-induced aggression. Several studies, *e.g.*, Azrin, Hutchinson, and Sallery (1964), have demonstrated that many species will react to an aversive stimulus by an aggressive attack on a nearby object, either animate or inanimate. If the reset key became a target for aggression, pecks on this key, which are part of an aggressive pattern, would be recorded as superfluous reset re-

sponses. Since each of these pecks was punished, the aggressive reaction would be limited to punishment intensities which were sufficient to induce pain but too low to suppress the aggressive reaction.

Certain properties of the behavior were much less orderly under this procedure of punishing the reset response compared to the procedure in which punishment was contingent upon food responses under the PR schedule (Dardano and Sauerbrunn, 1964). With the latter procedure, pauses after reinforcement were proportional to the size of the completed ratio, breaks during a ratio occurred during longer PR steps, and reset responses usually followed strained ratios. With the present procedure, these regularities in performance were often lacking. After highly strained ratios, the subject would often complete the next higher ratio at a high and regular rate; pausing after reinforcement often was not proportional to the step of the PR

schedule, and reset responses occurred early in the PR sequence as well as after advanced steps under the high punishment levels. The difference in the orderliness of behavior under the two procedures is probably related to the difference in punishment frequency. When responses under the PR schedule were punished, a minimum of 50 punished responses was necessary before the PR could be recycled to the nonpunished condition.

With regard to the relationship between the extent of responding under higher PR steps and the severity of punishment, the results indicate that beyond a particular intensity of punishment, the highest PR step completed and the frequency of completing advanced PR steps did not increase consistently. Furthermore, under the punishment intensity that produced the practical limit of responding through the higher PR steps, the subjects were still occasionally resetting the PR schedule after completing only the first or second steps. Additional increases of punishment intensity did reduce the frequency of reset responses after the early PR steps. This final suppressing effect of punishment makes the index of "responses per reinforcement" an inappropriate measure of the degree of penetration of the PR schedule. Although the frequency of completing advanced PR steps might be identical under two shock intensities, inclusion of the shorter PR steps under the lower punishment level in calculating the average would yield a smaller value. This suppression of reset responses after the early PR steps by those punishment intensities which did not appreciably increase responding through the higher PR steps had the effect of reducing the rate of reinforcement. This would be one of the factors

responsible for the increased strain of the performances under these punishment intensities.

REFERENCES

- Appel, J. B. Aversive aspects of a schedule of positive reinforcement. *J. exp. Anal. Behav.*, 1963, 6, 423-428.
- Azrin, N. H. A technique for delivering shock to pigeons. *J. exp. Anal. Behav.*, 1959, 2, 161-163.
- Azrin, N. H. Time-out from positive reinforcement. *Science*, 1961, 133, 382-383.
- Azrin, N. H., Hake, D. F., Holz, W. C., and Hutchinson, R. R. Motivational aspects of escape from punishment. *J. exp. Anal. Behav.*, 1965, 8, 31-44.
- Azrin, N. H., Hutchinson, R. R., and Sallery, R. D. Pain aggression toward inanimate objects. *J. exp. Anal. Behav.*, 1964, 7, 223-228.
- Dardano, J. F. and Sauerbrunn, D. Selective punishment of concurrent progressive-ratio performance. *J. exp. Anal. Behav.*, 1964, 7, 51-65.
- Findley, J. D. Preference and switching under concurrent scheduling. *J. exp. Anal. Behav.*, 1958, 1, 123-144.
- Herrnstein, R. J. Some factors influencing behavior in a two-response situation. *Trans. N.Y. Acad. Sci.*, 1958, 21, 35-45.
- Hodos, W. and Kalman, G. Effects of increment size and reinforcer volume on progressive-ratio performance. *J. exp. Anal. Behav.*, 1963, 6, 387-392.
- Thompson, D. M. Escape from S^D associated with fixed-ratio reinforcement. *J. exp. Anal. Behav.*, 1964, 7, 1-8.
- Thompson, D. M. Punishment by S^D associated with fixed-ratio reinforcement. *J. exp. Anal. Behav.*, 1965, 8, 189-194.
- Verhave, T. Towards an empirical calculus of reinforcement value. *J. exp. Anal. Behav.*, 1963, 6, 525-536.
- Weiner, H. Preference and switching under ratio contingencies with humans. *Psychol. Rep.*, 1966, 18, 239-246.
- Zimmerman, J. and Ferster, C. B. Some notes on time-out from reinforcement. *J. exp. Anal. Behav.*, 1964, 7, 13-19.

Received 29 June 1967.