SELECTIVE PUNISHMENT OF CONCURRENT PROGRESSIVE RATIO BEHAVIOR¹

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Key pecking of pigeons was reinforced with grain on a progressive ratio schedule during the presence of either of two key colors. Under one color, all responses were shocked; under the other color, responses were not shocked. A single response on a second key switched the key color and reset the progressive ratio, provided that the first step of the progressive ratio had been completed. A preference developed for the longer ratios of the progressive ratio under the non-shock key color. When the severity of punishment suppressed responding under the key color correlated with shock, the subjects continued to switch to the shock condition after a moderate degree of responding under the non-shock condition. Severe punishment also resulted in frequent, ineffective responses on the switching key and extended pausing under the key color associated with shock.

When two operants were concurrently maintained and independently reinforced, the response rate and relative frequency of each operant reflected the nature of the schedules (Ferster and Skinner, 1957). Characteristics of behavior which can appear under concurrent scheduling include the more frequent emission of one operant relative to the other and the frequency of alternation of the two operants. In a comprehensive investigation of preference under concurrent schedules, Findley (1959) added a switching operant which effected a change of the reinforcement contingencies. His results demonstrated that preference and switching were under control of the reinforcing and switching contingencies and suggested that the intermediate switching operant and the operants associated with primary reinforcement comprised a behavioral chain.

The present study employed the switching procedure to investigate the effects of punishing one of two operants, both of which were reinforced on the same progressive ratio schedule. Since progressive ratio reinforcement

schedules result in increasingly unfavorable reinforcement contingencies, emission of the non-punished operant would produce less favorable conditions for its further emission. Accordingly, the difference in strengths of the punished and non-punished operant would change. This continuous modification in the relative strengths of the operants, produced by the organism's behavior, should provide a sensitive measure of the behavioral effects of the aversive stimulus. In addition to possible local and overall rate changes of the punished operant and the degree of preference for the non-punished operant, the apparent development of an operant chain provides the opportunity to analyze the effect of punishment on non-punished operants which are intimately linked with the selectively punished operant.

METHOD

Subjects

Two male White Carneaux pigeons with short histories on intermediate fixed ratio schedules were used. Post-session body weight was maintained at 75% for B-44 and 80% for B-53. The pre-session weight of B-44 averaged 73% $\pm 2\%$; of B-53, 78% $\pm 1.5\%$. Average resistance values were 931 ohms for B-44 and 949 ohms for B-53. Subjects (Ss) were housed in separate units with continuous access to grit and water. Neither S had prior experience with electric shock.

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Apparatus

The experimental chamber was a 14 by 15 by 14.5 in. cubicle housed within a refrigerator compartment which incorporated a speaker for masking noise and an air blower. Two translucent keys, operated by a force of approximately 15 g, were mounted 9.5 in. from the mesh floor and equidistant from the midline of the front panel. The center-to-center separation of the keys was 2 in. The right key was illuminated by a red or green lamp; the left key by a white lamp. The opening to the food magazine was centered on the front panel. Two white lamps at the top-rear of the cubicle provided ambient illumination. Reinforcement was a 3 sec exposure to a raised feeder. The food hopper supply consisted of a mixed grain which did not pass $\frac{1}{8}$ in. sifting holes. The smaller grain was included in the post-session feeding.

The electric shock was derived from a 60 cps line voltage which was passed through a step-up transformer and a variable autotransformer. This circuit was introduced by a relay into a series circuit consisting of the S, a 10 K fixed resistor, and a milliammeter. Shock was delivered to the S by fixed electrodes (Azrin, 1959). Electrical resistance of the S was measured before and after each session. In this report, shock intensity is specified in terms of the milliammeter readings when a 1 K fixed resistor was substituted for the S and voltages of 20, 40, 60, 80, and 100 v were applied. The resulting magnitudes of current were 1.4, 3.0, 4.6, 6.2, and 7.8 ma. Duration of the shock was .05 sec.

Procedure

The progressive ratio (PR) reinforcement schedule consisted of an initial ratio of 50, and an increase in the size of each subsequent ratio by a fixed amount of 50 (50, 100, 150, etc). Responding on the right key, which was red or green, was reinforced by grain in accordance with the requirements of the PR. When the key was red, all responses on the key were shocked; when the key was green, responses on the key were not shocked. The left key, designated as the "switching key", was always illuminated by a white lamp. A single response on this key reset the PR to the first step of 50 and changed the color of the "food key" from red to green or vice versa. In

order for a response on the switching key to have these consequences, the first step of the PR on a given key color had to be completed. If a switching response occurred before the initial step was completed, the color on the food key did not change and the count on the ratio reverted to zero. Key lights were always illuminated except during operation of the magazine cycle. The food key was red at the start of each session with the following exceptions: the first seven sessions of B-44 and the first 10 sessions of B-53 when the starting color was alternated; a later part of the experiment in which the starting color was green for several consecutive sessions.

The duration of each daily experimental session was either 1 hr or delivery of all programmed reinforcements, whichever occurred first. Maximum number of reinforcements in a session was 80 for B-44 and 50 for B-53. The maximum number of color switches in a session was one less than the maximum number of reinforcements. Each experimental condition was continued until the behavior appeared stable for a minimum of five consecutive sessions. However, this criterion was extended informally due to the tendency of the behavior to shift abruptly after apparent stability and also to insure that the performance was not contaminated by extended effects of accidental changes in the contingencies occasioned by apparatus failure. Responses were recorded on a Gerbrands cumulative recorder with a gear substitution to increase running speed to 60 cm/hr. Frequencies of switching responses, responses on red, and responses on green were accumulated on electromagnetic counters. The order of administration of the experimental conditions and the number of reinforcements and shocks received under each condition are shown in Table 1.

RESULTS

Transient Effects of Shock

The shock contingency temporarily affected the PR behavior under the three lower shock levels for B-44 and the two lower shock levels for B-53. The next higher level of shock, 6.2 ma for B-44 and 4.6 ma for B-53 produced a non-transient effect on the PR performance. A sample of the baseline PR performance of B-44 and the transient effects of shock on this performance are shown in Fig. 1. Unless speci-

Table 1

Sequence of the Experimental Conditions and the Number of Sessions, Reinforcements, and Shocks under each Condition for Each *S*. All conditions included the Progressive Ratio Reinforcement Schedule.

Condition	B-44			B-53		
	Sessions	<i>S</i> ² 's	Shocks	Sessions	<i>S</i> ² 's	Shocks
No shock	61	4880	— —	70	3500	— —
1.4 ma	9	720	22339	7	350	11452
3.0 ma	12	960	31085	14	700	23549
4.6 ma	21	1547	46938	26	1300	28868
6.2 ma	30	1003	20195	24	440	4542
7.8 ma	15	59	1024	Not administered		
Max I-start green*	10	61	57	15	45	51
No shock	34	2353	— —	34	1563	— —

*The key color at the start of the session was changed to green and the shock intensity was the highest to which the *S* had been exposed, 7.8 ma for B-44 and 6.2 ma for B-53.

fied otherwise, each record represents a complete session. A response on the switching key reset the response pen and deflected the non-cumulative pen. The ratios on red are filled-in.

Fig. 1. Sample cumulative records showing pre-shock performance of B-44 and the transient effects of shock on the PR performance. The upper two records are complete sessions. The shock intensity and the number of the session under that intensity are listed above each record. Deflections of non-cumulative pen denotes switching responses. All responses shocked on red; responses not shocked on green.

The baseline PR performance of B-44, top curve, was characterized by frequent switching which ranged from 65 to 75, failure to proceed beyond the second step of the PR, frequent pausing after reinforcement on each key color, and immediate initiation of the ratio after the switching response was executed.

Addition of the shock contingency with the minimum intensity of 1.4 ma briefly disrupted behavior in the first session only (second record of Fig. 1). After the first shocked responses on red, B-44 returned to the switching key. Further shocked responses on red again resulted in responses on the switching key. Following this brief alternation of responding on both keys, two increments of the PR were completed rapidly on red. During the first half of the session, pauses between reinforcement and the switching response were longer on red than they were on green. A third feature of the initial reaction to shock was several instances of repeated responding on the switching key after the key color had been switched from green to red.

The next higher shock intensity, 3.0 ma, did not affect the behavior of B-44; however, when the intensity of shock was increased from 3.0 ma to 4.6 ma, the PR performance of B-44 was disrupted for several sessions. The records from the second and fourth sessions under this intensity are shown in Fig. 1. The record of the first session was not available due to failure of the recording apparatus. The disruption exhibited the same properties as those which appeared when the shock was initially introduced: alternation of responding on the switching key and on the food key, longer pauses after reinforcements on red compared to those on green, and response bursts on the switching key after the key color had been switched from green to red. The pausing and the ineffective switching responses persisted through the thirteenth session. In some ratios, the running rate was irregular. Also, B-44 stopped responding in some sessions, as seen in the second and fourth session in Fig. 2. The only instances of excessive responding on green were one run through the fourth increment and five runs through the third increment of the PR.

Illustrations of the baseline PR performance and the transient shock effects for B-53

Fig. 2. Sample cumulative records showing the pre-shock performance of B-53 and the transient effects of shock on the PR performance. Complete sessions are presented. The shock intensity and the number of the session under that intensity are shown above each record. Deflections of the non-cumulative pen denote responses on the switching key. All responses shocked on red; responses not shocked on green.

are shown in Fig. 2. Differences from the pre-shock performance of B-44 were the higher terminal rate and immediate switching after reinforcement. The lower-left record in Fig. 2 is the first session in which B-53 was exposed to shock. Intensity of the shock was 1.4 ma. As was the case with B-44, the initial reaction to the shock contingency was alternate responding on red and on the switching key. Note that three of the four penetrations past the first PR step were on red. Recovery of the pre-shock PR behavior occurred within the session.

Under a shock intensity of 3.0 ma, the PR performance of B-53 was affected in the first five sessions. As seen in the third curve of Fig. 2, B-53 drove through five increments of the PR on green shortly after the start of the first session under this shock level and frequently continued through the second and third steps of the PR during the remainder of the session. Seven of these 13 excursions occurred on red. During the early part of the session, the running rate on red was affected. These disruptions were not accompanied by an increased frequency of responses on the switching key. With the exception of a drive through four steps of the PR on green in the following session, penetrations of the PR in later sessions were limited to three increments. Occasionally, these continuations were on red.

Non-transient Effects of Shock

When the shock intensity was increased to 6.2 ma for B-44 and 4.6 ma for B-53, the performances of each *S* were modified in all sessions under these shock levels. An interesting property of these performances was periods of stable behavior extending over several sessions followed by an abrupt shift to another type of performance. Since the transitions were not identical for both *Ss*, the performances of each are presented in detail.

The performances of B-44 under the 6.2 ma shock intensity included three phases. The first was a reduction in responding which terminated in complete suppression; the second was a recovery of PR behavior which culminated in sustained drives into the PR on green; the third was a lower response frequency and absence of any inter-session trend. The first four and the seventh and eighth sessions under this shock intensity are shown in Fig. 3. In the initial session, symptoms previously noted under the lower shock intensities were apparent; namely, response bursts on the switching key after the color had been switched from green to red, occasional long pauses after reinforcement on red, and cessation of responding on the food key long before the termination of the session. Unlike the earlier performances, switching responses occurred during the periods of inactivity under red.

The disruption of behavior in the second session was more severe. Two features were especially prominent. The first was the extended pausing following the change from green to red with aperiodic responses on the switching key during these pauses. The second feature was the completion of the fourth PR step on green at a high, uniform rate. This was the first obvious occurrence of a preference for the longer ratios on green to the shorter, punished ratio on red by B-44. The rapid onset of the preference for green was evidenced further in the third session by the drive through the fifth increment of the PR on green and by the increased frequency of ineffective responses on the switching key under red. Note that after reinforcement on red, the switch to green occurred with little or no delay and that the run was initiated immediately on green. In earlier sessions, B-44 paused after reinforcement on red. During the fourth

Fig. 3. Sample cumulative records of the early PR performances of B-44 under a shock intensity of 6.2 ma. Each record is a complete session. The number of the session under this intensity is shown in front of each record. Deflections of the non-cumulative pen denote responses on the switching key. Responses on red shocked; responses on green not shocked.

session, B-44 emitted 107 responses on the switching key and five responses on red; in the fifth, one switching response; in the sixth, no responses.

A striking aspect of this sequence of performances was the frequent and vigorous responding on the switching key. A switching response formerly was executed by a rapid movement of the neck toward the switching key and a single or double peck on that key without changing the stance in front of the food key. The lateral movement was so rapid and fluid that it was often difficult to detect. In the present response bursts, a position was taken in front of the switching key, and responses were emitted in bursts without any orienting responses toward the food key.

The second phase of the performance under this shock level, which started in session 7, was a recovery of behavior which terminated in extended drives into the PR on green. The cumulative records from sessions 7 and 8 are shown in Fig. 3. In session 8, a response on the switching key just prior to the completion of the first PR step on red reset the count to zero. Note that the performance in session 8 exhibited properties of the pre-suppression behavior at this shock intensity: delays before initiating the run on red, aperiodic responses on the switching key during these delays, and the immediate initiation of responding on green after switching from red to green. In the ninth session, 3764 responses were emitted and 62 reinforcements delivered despite the

absence of responding during the first half of the session. In the following six sessions, the performances displayed extreme inter-session variability in terms of reinforcements (15 to

40), responses on the food key (1628 to 4475) and switching responses (15 to 79). Long delays prior to initiation of the first PR step on red and frequent responding on the switching

B-44 62 MA

Fig. 4. Sample cumulative records showing the later performances of B-44 under a shock intensity of 6.2 ma. Parts of the session in which no responses were emitted are not shown. Session number listed in front of each record. Deflections of the non-cumulative pen denote responses on the switching key. Responses on red shocked; responses on green not shocked.

key were usually present. Occasionally, drives into the PR on green occurred. In all sessions, B-44 responded more frequently on green. Occasional failure of the shocking circuit and ratio stepper undoubtedly contributed to this variability.

In the eighteenth session, a behavior pattern emerged which was stable through the 21st session. Records of sessions 18 and 21 are shown in Fig. 4. The prominent feature of these performances was the extended drives into the PR on green. In these excursions, which usually appeared during the early part of the session, switching did not occur after a ratio was initiated, and the pauses after reinforcement usually increased at successively higher steps of the PR except when a switching response followed reinforcement. In the latter part of each of these four sessions, post-reinforcement pauses on red tended to increase, and the response rate on green appeared more irregular than that on red.

The final type of PR behavior under this shock level, which exhibited many of the properties of the performances in the four preceding sessions, was distinguished by a reduction of responding on red. This phase began in session 22 and continued through the last session under this shock intensity. The lower three records of Fig. 4 illustrate this final behavior. The greater part of each session consisted of responding on the higher PR steps under green. Session 23, shown in Fig. 4, contained the maximum frequency of responses on red for these 10 sessions. The longer pauses after reinforcement on red relative to green, noted in sessions 18 through 21, were absent. On three occasions, B-44 continued through the second PR step on red.

Sessions 26 and 30 contain examples of a characteristic which developed in this final phase: cessation of responding after completion of an advanced PR step on green. This inactivity under green increased the alternative behaviors available at this point. These alternatives include (a) continue working on green, (b) switching to red and working on the shortest ratio under punishment, (c) inactivity. Formerly, B-44 usually stopped responding in the session after switching from green to red which resulted in only two behaviors available in the situation. This earlier behavior is illustrated in most of the sessions in Fig. 3.

Permanent modifications of the PR behavior of B-53 occurred with a shock intensity of 4.6 ma. The modifications in the PR behavior by punishment differed from those of B-44 in two respects: an initial suppression was absent and the final performance exhibited less deterioration. Sample performances of B-53 under this shock level are shown in Fig. 5. In the first session, top record in the figure, the first 10 min were characterized by alternation of responding on the switching key and on red. The letter "A" indicates a region in which a premature response on the switching key reset the count to zero shortly before completion of the first step. In the first session, there were several instances of appreciable responding on red followed by a switching response. Also, bursts of responses on the switching key usually occurred after the change of key color from green to red. Despite the severity of the disruption at the start of the session, there was only one instance, indicated by "B" in the record, in which a pause preceded responding on red.

Fig. 5. Sample cumulative records of the PR performance of B-53 under a shock intensity of 4.6 ma. Complete sessions are shown. The number of the session under this intensity is listed in front of each record. Deflections of the non-cumulative pen denote responses on the switching key. Responses on red shocked; responses on green not shocked.

In sessions 2 through 10, B-53 exhibited the variable inter-session behavior noted previously for B-44. In each of these sessions, the full quota of 50 reinforcements was delivered; however, the frequency and the degree of the penetrations into the PR on green differed among the sessions, and the response rate on green displayed various degrees of irregularity. In the eleventh session, a type of performance emerged which was stable through the eighteenth session. Sessions 12 and 18 are shown in Fig. 5. The salient characteristics of this performance were extended drives through the PR on green and an irregular rate on red. The running rate at the higher PR steps on green was uniform and high. Switching responses after initiating a ratio were extremely infrequent as were redundant responses on the switching key. In these eight sessions, two inter-session trends were present: the extended drives into the PR occurred earlier in successive sessions, and the accelerated rate on red changed to an irregular rate.

An abrupt transition to the final form of behavior observed under this shock intensity occurred in the nineteenth session. A similarity to the final transition of B-44 was the reduction in response frequency relative to the response frequencies in the preceding sessions. In the case of B-44, this reduction resulted from extended periods of inactivity; with B-53, the absence of prolonged drives into the PR produced the response decrement. Performances in sessions 19 and 24 are shown in the lower two records in Fig. 5. The overall rate in session 19 was lower relative to the later sessions due to the longer pausing after completion of the first PR step on green (an example is indicated by the letter "C") and the low, irregular rate on red. The only obvious modification of the PR performances in sessions 20 through 26 was the drives beyond the second PR step on green. As seen in session 24, the second increment of the PR occasionally was completed on red.

Since the next higher level of shock for each S suppressed their PR behavior, the shock levels of 6.2 ma for B-44 and 4.6 ma for B-53 were the only shock intensities which resulted in a modified PR performance. Summary data which compare the PR performance before addition of the shock contingency to the final performance under these shock levels for both Ss are shown in Table 2. The side-

Table 2

Comparison of Pre-shock Performance and Final Performance under the Shock Level Resulting in Non-transient Effects for Each S. Data Based on Final Five Sessions under 6.2 ma for B-44 and under 4.6 ma for B-53. Entries are Means of Five Sessions unless Indicated Otherwise.

	<i>B-44</i>		<i>B-53</i>	
	<i>Pre-shock</i>	<i>6.2 ma</i>	<i>Pre-Shock</i>	<i>4.6 ma</i>
Overall Rate-				
R's/sec	2.1	.7	3.0	2.1
R's in Session	4457	2452	2964	3232
R's on				
Red/Total R's	.51	.13	.55	.34
S ^R 's in Session	80	19	50	50
S ^R 's on				
Red/Total S ^R 's	.51	.24	.52	.40
Switching Key				
R's/Switches	1.6	6.1	1.4	1.2
<i>PR Step</i>				
	50	167	12	75
Final PR Step	100	15	7	9
Completed on	150	1	4	2
Green before	200	0	1	0
Switching—	250	0	0	0
Total Frequency	300	0	3	0
of Five Sessions	350	0	1	0
	550	0	1	0

heading "Final PR Step Completed on Green before Switching" indicates the extent to which the Ss penetrated the PR. For example, on one occasion under 6.2 ma, B-44 completed the eleventh PR step, which required 550 responses, then switched to red. The frequencies listed for each PR step are the total frequencies of the last five sessions. The remaining entries are the means of the last five sessions. For the three indexes which are ratios, the means were computed from the five session ratios.

The index "Switching Key R's/Switches," which is the ratio of the total number of responses on the switching key in a session to the number of actual color switches in the session, reveals that B-53 emitted slightly more extraneous responses on the switching key in the pre-shock sessions than in the final sessions under 4.6 ma. However, extraneous switching responses by B-53 were frequent in many of the transitional sessions under 4.6 ma and also during the transient reactions under the lower shock levels. It might be noted that the extra responses on the switching key during the pre-shock performances resulted mainly from rapid double pecks.

Figure 2 also shows that B-44 responded less frequently and B-53 more frequently in these shock sessions relative to their respective response frequencies in the pre-shock sessions. This difference was due to the extended pauses under red and the cessation of responding in the final behavior of B-44 under 6.2 ma, and the absence of such prolonged periods of inactivity in the final behavior of B-53 under 4.6 ma. Therefore, both Ss penetrated the PR more frequently under these shock levels relative to their pre-shock performances, but only B-53 exhibited a higher response frequency in the shock sessions.

Suppression of Behavior

Suppression of the PR behavior occurred under the next higher intensities of shock,

7.8 ma for B-44 and 6.2 ma for B-53. Performances of B-44 during four of the sessions are shown in Fig. 6. In the first session, top record of Fig. 6, B-44 exhibited a reduction of responding on red, a prolonged pause before initiating the first ratio on red, and extended excursions into the PR on green. The drives through the PR on green were attenuated in the second session. A similarity between these performances and the early performances of B-44 under 6.2 ma was the concurrent increase of responses on the switching key and decrease of responses on the food key. Both the first and second sessions terminated after a completed ratio at an advanced PR step on green. This characteristic was noted earlier for B-44. No responses were emitted from the third through the sixth session. A brief recovery occurred in

Fig. 6. Sample cumulative records showing the suppression of the PR behavior of B-44 by a shock intensity of 7.0 ma. Complete sessions are presented. Session number shown in front of each record. Deflections of the non-cumulative pen denote responses on the switching key. All responses shocked on red; responses not shocked on green.

the seventh session, shown in Fig. 6, which featured an extended pause and 276 responses on the switching key after the key color was switched from green to red. In sessions 2 and 7, B-44 responded frequently on the switching key under red and upon the completion of the first PR increment on red immediately switched to green, yet responded on green a relatively short time before switching back to red. In the eighth and ninth sessions, only switching responses were emitted. Responding on red reappeared briefly in session 10 (bottom record of Fig. 6). The only instance of responding in sessions 11 through 15 was five switching responses in session 12.

The suppression of B-53's PR behavior extended over a longer period and included more varied performances than that of B-44. Sample records of these performances are shown in Fig. 7. The initial reaction to the higher shock intensity contrasted sharply with the performances in the preceding session (compare to session 24 in Fig. 5). However, the accelerated rate on red and the sustained drives into the PR on green in the first session were present during transient phases at the preceding shock intensity (compare to session 12 in Fig. 5). Note the brief post-reinforcement pause before switching to red after the strained eighth step of the PR.

The performances in sessions 2 through 10 were extremely stable. An example is session 6 shown in Fig. 7. A low, irregular rate replaced the accelerated rate in red. Long delays often preceded the first response on red, and a high, uniform rate appeared toward the end of the ratio. Switching occurred immediately after reinforcement on red and after variable intervals following reinforcement on green. Unlike B-44, B-53 did not respond on the switching key during the prolonged pauses preceding the first response on red. Extended excursions into the PR on green occupied most of each session. Occasionally, the rate deteriorated during an advanced PR step on green, illustrated by the second occasion of responding on green in session 6.

This stable pattern of behavior shifted abruptly to another form in session 11, shown in Fig. 7, which persisted through session 14. The properties of this performance indicated a greater strain. Excursions into the PR on green were attenuated, and the response rate on green deteriorated at lower steps of the PR.

Pauses before the first response on red were longer and consistently present. The burst of responses on the switching key was the first recurrence of this behavior in the last 36 sessions.

Indications of further strain occurred in the fifteenth session, shown in Fig. 7. These included a pause of approximately 30 min before completion of the first ratio on red, continuation through the second PR step on red, and alternate responding on the switching key and on red. The seventeenth session, also shown in Fig. 7, contained a dramatic reaction by B-53. A total of 910 responses were emitted on the switching key. When continuous responding on red did occur, a switching response just prior to the end of the ratio reset the count. In sessions 18 through 24, response frequencies on red were respectively 13, 18, 13, 16, 2, 1, and 0; and on the switching key, 57, 96, 12, 13, 7, 3, and 9. The failure to remain on green when it was available after frequent, ineffective responses on the switching key under red, previously noted in the behavior of B-44, was shown by B-53.

Both Ss exhibited a higher frequency of ineffective switching responses during advanced stages of the suppression of PR behavior. In the case of B-44, these responses occurred aperiodically during extended pauses under red; with B-53, the responses occurred in bursts or, less frequently, in alternation with responses on the red key. Another common feature of the performances of B-44 and B-53 was the shortening of drives into the PR on green concurrent with the heightened suppression of responding on red. These drives on green were at their maximum during the first session of B-44 and the early sessions of B-53. With continued exposure to these shock levels, the length of these excursions diminished.

Reversal of Starting Color

With the exception of a few early sessions, the color of the food key was red at the start of the session and could not be switched to green until the first PR step of 50 had been completed on red. This contingency occluded behavior on green when the shock level effectively had suppressed responding on red. In order to investigate the properties of the behavior under the non-shock color when responding on red was suppressed, the food key

Fig. 7. Sample cumulative records showing the suppression of the PR performance of B-53 by a shock intensity of 6.2 ma. Complete sessions are shown. Number of the session is listed before each record. Deflections of the non-cumulative pen denote responses on the switching key. Responses on red shocked; responses on green not shocked.

color was changed to green at the start of the session. All other factors were unchanged.

Three of the 11 sessions of B-44 under this condition are shown in Fig. 8. In the first session, top record in the figure, B-44 reacted to the change in starting color by responding immediately on green and completing eight PR increments at a high rate. A single break of approximately 1 min occurred during the first increment. No responses were emitted on red after the color was switched. The behavior was similar in the second and third sessions; four responses were emitted on red in the second session. In the fourth session, shown in Fig. 8, appreciable strain was present. Note the extended pauses after the completion of each PR increment and the break of approximately 20 min during the ninth increment. The switching response immediately after reinforcement on the ninth step is a further illustration of the rapid change of contingencies after reinforcement on a strained ratio. The extended drives under green, which were characteristic of the first four sessions, were absent in the fifth session. In the fifth session, bottom record of Fig. 8, B-44 switched to red after an abbreviated number of PR steps on green and responded aperiodically on the switching key during the remainder of the session. The suppression of responding on red continued through all

later sessions. In most of these sessions, B-44 switched to red shortly after the start of the session as shown in session 5 of Fig. 8. Occasionally, B-44 paused for long periods after the second or third step of the PR on green.

The transitional behavior of B-53 under the reversed starting color differed from that of the B-44; however, the final behavior was similar. Records from five sessions under this condition are shown in Fig. 9. In contrast to the sustained drive on green by B-44 when the condition was introduced, B-53 did not complete a ratio on green until the third session. The upper-left segment in Fig. 9 contains all responses emitted in the first session. Nine responses were emitted on green before a response on the switching key reset the count. In the second session, three responses on green were followed by a response on the switching key. The upper-right segment in Fig. 9 is from the third session in which two reinforcements were obtained under green; however, the color was switched to red shortly after the second reinforcement. The break in the first increment and the uniform rate in the second were similar to the first ratios completed by B-44 on green. The three bursts on the switching key totalled 51 responses. The behavior was similar in the following four sessions except that responding on green was initiated earlier in the session. The middle-left curve in Fig. 9 is the fourth session. Extended drives into the PR on green, similar to those of B-44, appeared in the eighth session. All responding in this session is shown in the middle-right segment of Fig. 9. Note that the switching response occurred after an irregular rate in the seventh step of the PR. This form of behavior persisted in sessions 9 and 10.

The attenuation of the sustained drives on green, previously noted in the performances of B-44, occurred in the eleventh session for B-53. The complete session is shown in Fig. 9. In the four remaining sessions under this condition B-53 did not pursue the PR beyond the third step of 150. A dramatic feature of the performance in session 11 was the emission of 641 responses on the switching key. One burst extended over 5 min. This reaction was observed previously for B-53 but not in the same severity. Responses on the switching key in the last four sessions were 66, 31, 1, and 1 respectively.

Fig. 8. Sample cumulative records showing the performances of B-44 under a shock intensity of 7.8 ma with the key color changed to green at the start of the session. Parts of the sessions in which no responses were emitted are not shown. Number of the session is listed before each record. Deflections of the non-cumulative pen denote responses on the switching key. All responses shocked on red; responses not shocked on green.

B-53 6.2 MA

Fig. 9. Sample cumulative records showing performances of B-53 under a shock intensity of 6.2 ma with the key color changed to green at the start of the session. Segments from each session are shown. Session number listed before each record. Deflections of the non-cumulative pen denote responses on the switching key. All responses on red shocked; responses on green not shocked.

The availability of the green key at the start of the session did not affect the suppression of responding on red. Both B-44 and B-53 switched to the punishment contingency under red early in the session after completion of a few steps of the PR on green, but few responses then were emitted under red. The suppression of one operant by severe punishment was not associated with a pronounced preference for working under or remaining under the non-punished condition. The S continued to execute the mediating response which reinstated the punishment condition.

Removal of the Shock Contingency

Following the final session with the reversed starting color, the shock contingency was removed and the starting color was returned to red. The pre-shock performance of B-44 ap-

peared in the fifth session and stabilized by the sixteenth session. Cumulative records of the first five sessions are shown in Fig. 10. Responding on red occurred in the first session. Following an extended pause, the first ratio on red was completed rapidly. Although responses on red were not shocked, the switch to green was executed immediately after reinforcement and a drive through four steps of the PR was initiated. The persistence of this behavior in the first three sessions attests to the strong conditioned aversive property acquired by the red key color. Note that these sessions terminated with B-44 at an advanced increment of the PR on green. Also, the earlier onset of responding in the successive sessions had been observed in previous sessions during an inter-session recovery. The recurrence of frequent responding on red by B-44 appeared

Fig. 10. Sample cumulative records showing the PR performance of B-44 after removal of the shock contingency. Parts of the session in which responding was absent are omitted. Number of the session listed before each record. Deflections of the non-cumulative pen denote responses on the switching key.

in the fourth session. The only indication of the previous disruption was the extended pause before initiating the third PR step on green. Notice the immediate switch following completion of the third PR step. In session 5, the pre-shock performance was regained, but in the following 10 sessions, the overall rate exhibited a fair degree of variability due to the irregular duration of the pauses between reinforcement and the switching response.

The recovery of pre-shock PR performance by B-53 also contained a brief transitional phase in which the red key color continued to exert control over the behavior. As with B-44, this control terminated abruptly. Segments from the first three and the complete fourth and sixth sessions are presented in Fig. 11. The performances in the first two sessions resembled the performances in the first two sessions under the previous condition in which the starting key color was reversed. (Compare to session 1 in Fig. 9). The third session contained another striking example of repetitive responding on the switching key. Responses on this key during the 1 hr session totalled 371.

Fig. 11. Sample cumulative records showing performances of B-53 after removal of the shock contingency. Number of the session is listed before each record. Deflections of the non-cumulative pen denote responses on the switching key.

When a ratio on red was completed in the third session, B-53 duplicated the behavior of B-44 by switching the key color immediately after reinforcement and continuing through four increments of the PR on green. In the following session, lower-left record of Fig. 11, frequent responding on red in conjunction with the absence of prolonged responding on green illustrated the abrupt loss of control of the prior shock contingency. Seven of the 10 instances in which B-53 continued through the second PR step were under red. In the sixth session (lower-right record), the pre-shock PR behavior was recovered. Note that all instances of responding past the first PR step were on red. The inter-session variability in overall rate during recovery shown by B-44 was not exhibited by B-53.

DISCUSSION

The three operants in this experimental situation were a reinforced response on green, a reinforced and punished response on red, and the switching response. The strength of each food-reinforced operant was the resultant of opposing influences. Pecking on red was maintained by the primary reinforcement of grain but had the aversive consequences of response-contingent shock and the increased response requirement of the progressive ratio schedule. Responding on green also was maintained by the primary reinforcer and had the aversive consequence of an increasing response

requirement for successive reinforcements. Since the positive reinforcer and the reinforcement schedule were common to both operants, the probability of responding on red or green was a function of the relative aversiveness of "shock plus more work" on red and "more work" on green.

The emission of responses under the PR schedule not only reflected the relative strengths of the events controlling each operant at the time but also modified the relative strengths. With an aversive value of shock, the probability of responding on the first PR step on green would be higher than the probability of responding on the first PR step on red. If the size of the second PR step was insufficient to counteract the aversiveness of responding on red, responding would be initiated on the second step. At some point in the PR, the work required for reinforcement would be of sufficient magnitude to create a more aversive condition than that of responding on red. This point would be the occasion for the switching response, which was maintained by the secondary reinforcer of a change to the key color associated with the less aversive condition. The number of responses in the final completed ratio of a PR schedule has been used as a measure of the strength of a reinforcing event (Hodos, 1961; Hodos and Kalman, 1963).

A further determinant of response probability was the accumulated count on a given ratio (Ferster and Skinner, 1957). Within a ratio of the PR, the discriminative stimulus of the count would diminish the aversiveness of further responding under a color. This factor would explain the completion of an advanced PR step on green despite severe strain in the ratio and also the brief pause before executing the switching response after reinforcement on that ratio. The rapidity of the switch after this reinforcement would be due to the discriminative stimulus of zero count on the subsequent ratio which would abruptly increase the aversiveness of further responding on green. For this reason, post-reinforcement pauses increased with successive steps of the

PR, with the exception of the last step completed before switching.

The behavior generated by these experimental contingencies provided several indicators of the momentary strength of each food-reinforced operant. These indicators include duration of post-reinforcement pausing prior to initiating the next step of the PR, extent of the excursions into the PR, and latency of the switching response following reinforcement. The general preference of the S for a given reinforcing contingency, defined as the relative frequency of responding under that contingency, is based on a longer time sample of behavior.

Two properties of the behavior under severe punishment are not easily interpreted by the controlling variables which have been discussed. The first was the occurrence of frequent and vigorous responding on the switching key. This result can only be identified as one of the disruptive effects of severe punishment on the chained behavior. The second aspect of the behavior not easily interpreted was the failure to continue responding on green or remain under green after responding on red was suppressed by punishment. This was illustrated clearly where the sessions were started with the food key green. Possible explanations are an increased aversiveness of green after completing extremely long ratios under this color or extinction of responding under the longer PR steps on green.

REFERENCES

- Azrin, N. H. A technique for delivering shock to pigeons. *J. exp. Anal. Behav.*, 1959, 2, 161-163.
- Ferster, C. B. and Skinner, B. F. *Schedules of reinforcement*. New York: Appleton-Century-Crofts, 1957.
- Findley, J. D. Preference and switching under concurrent schedules. *J. exp. Anal. Behav.*, 1958, 1, 123-144.
- Hodos, W. Progressive ratio as a measure of reward strength. *Science*, 1961, 134, 943-944.
- Hodos, W. and Kalman, G. Effects of increment size and reinforcer volume on progressive ratio performance. *J. exp. Anal. Behav.*, 1963, 6, 387-392.

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