FRACTIONAL PUNISHMENT OF FIXED-RATIO PERFORMANCE¹

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Key-peck responses of pigeons under a fixed-rate 60 (Exp. I) or fixed-ratio 99 (Exp. II) schedule of positive reinforcement were punished by response-dependent electric shock during a segment of the ratio. The punishing stimulus was scheduled in one of three locations: the first third of the ratio, the middle third, or the final third. At high shock levels, the different loci of punishment differentially affected the typical fixed-ratio performance pattern. Post-reinforcement pauses were lengthened by all punishment conditions but to a greater degree when the responses in initial third of the ratio were punished. Disruption of responses before the punished segment of the ratio was a conspicuous feature of the performances when the middle or final third of the ratio was punished. Two of the punishment conditions produced similar effects on both fixed-ratio baselines but punishing the final third of the ratio suppressed the punished responses of the ratio only with the fixed-ratio 99 schedule. General effects of all punishment conditions included consistent intra-session recoveries of partially suppressed performances, the rapid recovery of the FR performances after the punishment dependency was removed after complete suppression, and the facilitation of overall and/or local response rates of most subjects by low-intensity shock.

The behavior sequence controlled by a fixed-ratio (FR) reinforcement schedule, under which each reinforcement is dependent upon a given number of responses, is characterized by a high, regular response rate following a pause after reinforcement. Investigations that have scheduled a punishment dependency during each sequence of responses have shown that the modification of this bi-valued rate in each sequence, or ratio, is dependent partly on the frequency and locus of the punishing stimulus. Punishing each response of a short FR increased the duration of the post-reinforcement pauses but did not suppress the running rate during the ratio (Azrin, 1959b). This result also occurred when punishment was limited to the first response of each ratio; however, punishing the middle or final response of the ratio disrupted the responding before the punished response as well as lengthening the post-reinforcement pauses (Dardano and Sauerbrunn, 1964b). Holz (1967) reported that selec-

tively punishing each component of a chained FR schedule produced different temporal patterns of responding and that the responses preceding the punished segment were suppressed more than the punished responses. Local reductions in running rate also occurred when the intensity of the punishing stimulus increased in discrete steps during the FR, but did not occur when the intensity decreased (Dardano and Sauerbrunn, 1964a). Lyon (1964), using the Estes-Skinner conditioned suppression procedure, showed that the conditioned stimulus produced complete suppression only if presented early in the ratio.

The different effects of various punishment loci on FR performance can be integrated to a degree by considering some factors controlling FR behavior. Ferster and Skinner (1957) viewed the response sequence during the ratio as a response chain with number of responses since reinforcement acting both as a discriminative stimulus, demonstrated by Rilling (1967, 1968), and as a conditioned reinforcer. The reinforcing strength of response number was assumed to increase as number of responses in the ratio increased. Within this framework, the resistance of the response sequence to disruption by punishment would be ascribed to the chained nature of the sequence. In addition, responding early in the ratio would be more susceptible to the

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suppressing action of punishment. Also, scheduling punishment in a particular part of the ratio would permit the acquisition of conditioned aversive properties by stimuli preceding the onset of punishment. These conditioned aversive stimuli would exert a suppressing effect on the pre-punished responses of the ratio.

The present study further analyzed the effects of selectively punishing a response sequence maintained by a FR schedule of reinforcement by making the punishing stimulus dependent on responses comprising either the first third, the middle third, or the final third of the ratio. In the initial experiment, these punishment conditions were superimposed on an FR 60 reinforcement schedule; in the second experiment, on an FR 99 schedule. The analysis was concerned primarily with differential effects of the three loci of punishment on the temporal pattern of responding, the relative degree of suppression by the punishment conditions on the punished and unpunished responses of the ratio, and the comparability of the effects of a given punishment locus on performance maintained by different size FR schedules.

METHOD

EXPERIMENT I

Subjects

Eight adult White Carneaux pigeons were experimentally naive. Each pigeon was maintained at a fixed percentage of free-feeding weight, 75% to 80%, depending on the subject, throughout the study. They were housed in individual compartments with continuous access to grit and water.

Apparatus

The experimental chamber, 15 in. (31 cm) high, 16.5 in. (35 cm) long, and 14.75 in. (30 cm) deep, was set within a sound attenuating compartment and was furnished with an air blower, speaker for masking noise, a relay for response feedback, and a grain dispenser. A translucent response key, mounted in the center of the front panel and 10 in. (25 cm) above the grid floor, was transilluminated by a 6-w white lamp. Two 6-w lamps mounted at the top rear of the chamber provided gen-

eral illumination. Reinforcement was a 3-sec presentation of the grain magazine located below the response key.

The punishing stimulus was a 50-msec pulse of 60 Hz ac. The basic shock circuit included a step-up transformer, auto-transformer, milliammeter, and a 10,000 ohm resistor. The shock was delivered to the subject through silver electrodes implanted around the pubis bones (Azrin, 1959a). Shock intensity was determined by shorting the output and pre-setting the desired intensity on the milliammeter. The electrical impedances of the subjects ranged from 500 ohms to 1300 ohms as measured by a bridge circuit using a 7-v 60-Hz input. All scheduling and recording equipment were located in an adjacent room.

Procedure

After preliminary training that consisted of response shaping and exposure to progressively higher FR schedules, each subject was exposed to the FR 60 positive reinforcement schedule for a minimum of 40 sessions. When the FR performance appeared stable over 10 consecutive sessions in terms of the overall rate, local rate, and time to complete successive thirds of the ratio, the subject was exposed to one of three punishment conditions. These conditions were response-dependent shock of the first 20 responses of the FR 60 (Shock 1-20), or the twenty-first through fortieth response (Shock 21-40), or the forty-first through sixtieth responses (Shock 41-60). The locus of the punished block of the responses was the only difference among the three punishment conditions. The shock intensity, initially 2 mA, was increased in small increments, usually 1 mA, for all subjects. Each intensity was scheduled for a minimum of seven sessions and was increased when the overall rates and intra-ratio rates did not show any trends over five consecutive sessions. When the FR performance was completely suppressed by a shock intensity, the punishment contingency was removed. The criterion for complete suppression was completion of less than three ratios totalled over five consecutive sessions. Maximum shock intensity for a subject refers to the intensity that produced the criterion of complete suppression. After removal of the punishment dependency a minimum of 20 sessions were scheduled. The general experimental procedure is summarized in Table 1. A third subject under

Table 1

Summary of the procedure for Exp. I. Shock intensities are in mA and listed in order of presentation. The number of sessions under each intensity is shown in parentheses. For subjects exposed to two punishment conditions, the temporal order of each condition is listed beside the subject number.

<i>Punishment Condition</i>	<i>Subject</i>	<i>Shock Intensities and Sessions</i>
Responses	B-167	0(71), 2(7), 4(15), 5(11), 6(22), 7(25), 8(16), 0(20)
1-20	B-32(1)	0(66), 2(29), 4(16), 5(15), 6(29), 7(29), 0(25)
Shocked	B-34(2)	0(45), 2(12), 4(11), 5(20), 6(25), 0(29)
Responses	B-16	0(70), 1(17), 2(8), 3(14), 4(11), 5(25), 6(25), 6.5(10), 7(22), 0(32)
21-40	B-32(2)	0(42), 2(11), 4(14), 5(11), 6(19), 0(25)
Shocked	B-34(1)	0(52), 2(21), 4(10), 6(22), 7(18), 8(30), 9(37), 0(20)
Responses	B-14	0(41), 2(8), 4(9), 6(9), 8(12), 10(13), 11(14), 12(10), 0(18)
41-60	B-19	0(50), 2(15), 4(10), 5(15), 6(15), 7(15), 0(35)
Shocked		

the "Shock 41-60" condition was injured and discontinued.

The daily experimental sessions terminated after 1 hr or after delivery of all scheduled reinforcements, whichever occurred first. The 40 scheduled reinforcements for the subjects approximately maintained experimental weight. Post-session feeding adjusted the weights upward when necessary. The subjects were weighed and their electrical resistances measured before and after each session.

EXPERIMENT II

Subjects

Nine male adult White Carneaux pigeons were maintained at 80% of free-feeding weight. Three pigeons, B32, B-16, and B-14, were subjects in Exp. I; the remaining subjects were experimentally naive.

Apparatus

The same as in Exp. I.

Procedure

The general procedure followed that used in Exp. I. The positive reinforcement schedule was FR 99, and one-third of the responses in each FR were punished. The three punishment conditions were shock dependent on the first 33 responses (Shock 1-33), on the thirty-fourth through sixty-sixth responses (Shock 34-66), or on the sixty-seven through ninety-ninth responses (Shock 67-99). The running procedure is summarized in Table 2.

RESULTS

The results of both experiments are presented jointly. Unless otherwise noted, the average values reported in this section are arithmetic means based on data from the final five sessions for each subject under a given experimental condition. In figures presenting cumulative response records, records are shown for the two subjects whose performances defined the range of inter-subject variation under a particular punishment condition.

First third of the FR punished. The prominent effect of punishing the initial third of the ratio in both the FR 60 and FR 99 performances was an increase in the average duration of post-reinforcement pauses in the session. The durations of individual pauses in the session were variable; brief pauses still occurred even under the maximum shock intensity. This punishment locus did not disrupt responses that followed the punished segment. Cumulative response records showing representative performances before application of this punishment dependency and under shock intensities that produced a suppressing effect are shown in Fig. 1 for the FR 60 schedule and in Fig. 2 for the FR 99 schedule. In Fig. 2, records of B-14 under the two highest intensities are not included because suppression was immediate under 7 mA and completed ratios were infrequent under 6 mA.

This punishment locus did exert some suppressing effect on the punished segment of the ratio. The extent of the direct suppression

Table 2

Summary of procedure for Exp. II. Shock intensities are in mA, and listed in order of presentation. The number of sessions under each intensity is shown in parentheses. The subject exposed to two punishment conditions has order of condition listed below the subject number.

Punishment Condition	Subject	Shock Intensities and Sessions
Responses 1-33 Shocked	B-14	0(27), 2(13), 3(19), 4(13), 5(15), 6(13), 7(6), 0(30)
	B-29(2)	0(27), 2(8), 3(8), 4(15), 5(20), 6(14), 0(33)
	B-32	0(41), 2(9), 3(11), 4(22), 5(15), 0(22)
Responses 34-66 Shocked	B-10	0(52), 2(16), 3(13), 4(20), 5(16), 6(10), 7(9), 8(12), 9(14), 10(11), 11(13), 12(18), 0(34)
	B-16	0(23), 2(11), 3(16), 4(14), 5(23), 5.5(20), 6(14), 6.5(8), 0(23)
	B-51	0(55), 2(9), 3(15), 3.5(23), 4(14), 4.5(14), 5(13), 5.5(33), 0(31)
Responses 67-99 Shocked	B-26	0(42), 2(15), 3(11), 4(10), 5(23), 6(16), 7(12), 8(17), 8.5(12), 9(16), 9.5(16), 10(7), 0(29)
	B-29(1)	0(44), 2(16), 3(14), 4(17), 5(25), 6(10), 7(25), 0(27)
	B-62	0(54), 2(9), 3(13), 4(10), 4.5(13), 5(16), 5.5(8), 6(17), 6.5(12), 7(14), 7.5(19), 8(15), 8.5(19), 9(12), 0(19).

Fig. 1. Cumulative response records of two subjects illustrating the effects of punishing the initial 20 responses of the FR 60. The pip in each ratio indicates the first unpunished response. The records of each subject under 4 mA show the first non-transient effect of punishment. Unless noted otherwise, these cumulative records and the cumulative records in later figures, (1) show complete sessions, (2) include a performance from the final session before scheduling punishment, (3) show the performance in the final session under the listed shock intensity except in the case of the maximum intensity, (4) include a transitional performance under the shock intensity that later produced complete suppression.

Fig. 2. Cumulative response records illustrating some effects of punishing the first 33 responses of the FR 99. The pip denotes the first unpunished response. The record for B-14 under 5 mA does not illustrate a performance during the transition to complete suppression.

varied widely among the subjects under a given FR schedule and, in most cases, was limited to a break shortly after starting the ratio. With the FR 60 schedule, only B-34 showed frequent response breaks in the punished segment before the maximum shock intensity. The remaining FR 60 subjects exhibited infrequent short breaks early in the ratio only during the transition to complete suppression. With the FR 99 schedule, a direct suppression of punished responses occurred in the performances of all subjects under the penultimate shock intensity but was conspicuous only in the performances of B-29. Examples of the performances of B-29 and B-14, which showed the maximum and minimum disruption of responding during the punished segment, are included in Fig. 2. Note that the slight disruption shown by B-14 under 4 mA, which consisted of an infrequent break early in the ratio, was absent under 5 mA.

Middle third of the FR punished. The two marked and general effects of punishing the responses comprising the middle third of the ratio were an increase in the average duration of post-reinforcement pauses and a partial suppression of responses preceding the punished segment of the ratio. These effects occurred with both FR schedules and appeared for most subjects only under near-maximum shock intensities. The responses following the punished segment in each ratio were never suppressed with either FR schedule. Sample performances under this punishment condition are shown in Fig. 3 for the FR 60 schedule and in Fig. 4 for the FR 99 schedule.

Although this punishment condition and punishment of the initial third of the ratio both produced lower response rates during the first third of the ratio, the temporal pattern of responding during this segment differed under the two punishment conditions, espe-

B-34 **B-16**

Fig. 3. Cumulative response records of two subjects showing the effects of punishing the twenty-first through fortieth response of the FR 60. The first pip in each ratio denotes the first punished response and the second pip denotes the first unpunished response. The records of each subject for 6 mA show the first non-transient effects of punishment.

cially with the FR 99 schedule. When the middle third of the ratio was punished, the response pattern included instances of negative curvature, frequent response breaks, long breaks following a burst of responses, and breaks late in the segment. When the initial third of the ratio was punished, the patterns in the first segment featured localization of breaks early in the segment, a high running rate during most of the segment, and absence of any decelerations in rate.

The increase in the average duration of pauses after reinforcement when the middle third of the ratio was punished was less than the increase produced by punishment of the initial third of the ratio. An index of this increase was calculated by dividing the average pause duration under the penultimate shock intensity by the average pause duration of the

pre-shock performances for each of the six subjects under each punishment condition, then averaging these six values for each condition. Punishing the initial third of the ratio increased pause duration by a factor of 10; punishing the middle third of the ratio increased pause duration by 6.4. Brief pauses also continued to occur during strongly suppressed performances when the middle third of the ratio was punished.

A direct suppressing effect of punishment on the shocked segment of the ratio was not as general nor as marked as the suppression of the preceding unpunished responses. The disruption in the punished segment usually consisted of alternate responses and brief breaks during the early part of the punished segment. The degree of direct suppression varied widely among the subjects under each schedule. With

the FR 60 schedule, this suppression of punished responses was maximum for B-34, whose records are shown in Fig. 3, and absent for B-32. Note that the strongly suppressed performances of B-34 often featured a sustained high rate up to the onset of the punished segment and that responding within the punished segment was often positively accelerated. All subjects under the FR 99 schedule showed a direct suppressing effect on responding early in the punished segment, but the effect was slight for two of the subjects. Note in Fig. 4 that B-51 exhibited response breaks in the punished segment under 5 mA but not under 5.5 mA, the second instance of a suppression of punished responses that did not persist under a higher shock intensity. The earlier case involved B-14 under the "Shock 1-33" condition. The records in Fig. 3 and 4 also illustrate the intra-session recovery of partially sup-

pressed performance that occurred consistently under both FR schedules.

Final third of the FR punished. Localizing the punishing stimulus in final third of the ratio was the only punishment condition that had a differential effect on the FR 60 and FR 99 performances. The punished responses of the ratio were partially suppressed under the FR 99 schedule but not under the FR 60 schedule. This direct suppression of punished responses in the FR 99 performances was limited to extremely high intensities, occurring under the penultimate intensity for two subjects and under the intensity producing complete suppression for B-62. In contrast, the local rate in the punished segment with the FR 60 schedule under shock levels that partially suppressed the unpunished responses in the ratio was higher than the local rate for this segment during the pre-punishment performances.

Fig. 4. Cumulative response records illustrating some effects of punishing the thirty-fourth through sixty-sixth response of the FR 99. The first pip indicates the first punished response and second pip indicates the first unpunished response. The records of both subjects for 4 mA show the first non-transient effects of punishment.

Other effects of this punishment condition were common to both FR schedules. The cumulative records of the FR 60 performances in Fig. 5 and the FR 99 performances in Fig. 6 illustrate the punishment effects. Figure 6 includes a single record of the performance of B-62 under the maximum shock intensity, since responding by this subject was suppressed only under this shock level.

This punishment locus disrupted the responses preceding the punished segment of the ratio with both FR schedules. As seen in Fig. 5 and 6, the disruption consisted of alternating runs and breaks of varied duration with breaks sometimes occurring in the latter part of the unpunished segment. The comparative suppression of the unpunished and punished responses in the ratio depended on ratio size. Under the FR 60 schedule, only unpunished responses were suppressed; under FR 99, the relative suppression in these segments varied among subjects. The specificity of the suppressing effect on the unpunished responses of the FR 60 performances is illustrated by the record in Fig. 5 for B-19 under 7 mA. In

some ratios, responding was disrupted up to the first punished response, then a high response rate was initiated immediately that persisted throughout the punished segment.

An increase in the duration of pauses after reinforcement was not a marked nor a consistent effect of this punishment condition with either FR schedule. Using the index described earlier, the increase in average pause duration under the penultimate shock intensity for the five subjects was 2.4 compared to 10.0 when the initial third of the ratio was punished and 6.4 when the middle third was punished.

The FR performances were more resistant to disruption when the final third of the ratio was punished compared to the other punishment conditions. A marked disruption occurred only under the maximum shock intensity for three of the five subjects.

Figure 7 summarizes the temporal variation in responding during the ratio under the three punishment conditions for the FR 60 performances, and Fig. 8 shows the same functions for the FR 99 performances. The graph for

Fig. 5. Cumulative response records of two subjects illustrating some effects of punishing the forty-first through sixtieth response of the FR 60. The pip indicates the first punished response. The record of B-14 under 7 mA shows the first non-transient effect of punishment.

Fig. 6. Cumulative response records showing the effects of punishing the sixty-seventh through ninety-ninth response of the FR 99. The pip indicates the first punished response. The record of B-29 for 3 mA shows the first non-transient effect of punishment. The single record of B-62 illustrates a performance during the transition to complete suppression.

each subject shows the average pause after reinforcement (PAR) duration and the average time to complete each third of the ratio as a function of shock intensity. Pre-punishment and post-punishment performances are included. For each of the final five sessions under a given shock intensity, the first ratio and an incomplete ratio, if any, at the end of the session were discarded, then the average time to complete each part of the ratio was calculated by dividing the cumulative time for that part by the number of ratios. These values for each session were averaged over the five sessions that yielded the points in each graph. The letter "S" above the highest shock intensity in the graphs of several subjects indicates that the performance eventually was suppres-

sed completely under this intensity. These values were included in order to provide additional data for those subjects whose performances showed little deterioration under the highest shock level that still permitted continued responding and also to show impairment in parts of the ratio during maximum strained performance. The data for these points were obtained in the following manner. Starting from the final session under this shock intensity and moving toward the first, those sessions were selected in which a minimum of six ratios were completed. If five such sessions were available for the subject, these data were included in the functions. The data points were calculated in the same manner as the other points. These resulting means are not

Fig. 7. The time required to complete various parts of the FR 60 as a function of shock intensity. The first and final sets of points refer to pre-punished and post-punished performances. The letter "S" above the highest shock intensity in the graphs of some subjects indicates that this intensity eventually produced complete suppression. Refer to text for further description of figure.

comparable to the other mean points for a given function because they are based on data from transitional performances.

Figures 7 and 8 show the general relationships: (1) the absence of any suppressing effect on responding until the shock intensity had exceeded 50% of the maximum value for each subject, (2) the absence of any suppressing effect on responses that followed the punished segment, (3) the suppressing effect on responses preceding the onset of punishment. A comparison of the functions across punishment conditions shows the following: (1) the occurrence of disrupted responding later in the ratio when the final third was punished relative to the locus of disruption under the other punishment conditions, (2) the increase in duration of post-reinforcement pauses as a marked effect

when the initial third of the ratio was punished, less marked when the middle third was punished, and least marked when the final third was punished, (3) a partial suppressing effect on responses in the first third of the ratio becoming more prominent than the lengthened post-reinforcement pauses under punishment of the middle or the final third of the ratio compared to punishment of the initial third of the ratio, (4) the greater suppressing effect on the responses preceding onset of punishment than on the punished responses of the ratio when the middle third of the ratio was punished. Finally, comparison of the FR 60 and FR 99 performances under punishment of the final third of the ratio shows the only marked effects of punishment that depended on the ratio size: (1) the suppression of pun-

ished responses in the ratio only with the FR 99 schedule, (2) a greater suppressing effect on the responses preceding onset of punishment than on punished responses of the ratio only with the FR 60 schedule.

Besides the suppressing effect of high-intensity shock, a facilitating effect of low-intensity shock in the form of a higher overall and local response rates and a reduced post-reinforcement pause duration was a common property of the performances. An index of the facilitation of a particular rate for a subject was calculated by subtracting the average pre-punishment rate from the average rate under the shock intensity that yielded the greatest increase over the pre-punishment rate, then dividing by the pre-punishment rate. Under

the FR 60 schedule, five of the eight subjects showed a facilitation of overall rate ranging between subjects from 4% to 23% with median of 8%, and four subjects showed a higher running rate ranging from 7% to 17% with a median of 12%. Seven of the eight FR 60 subjects had a higher local rate in at least one of the three segments of the ratio, the most notable instances occurring under the "Shock 41-60" condition with both subjects showing an increase in rate during the punished segment of 29%. Under the FR 99 schedule, eight of the nine subjects exhibited a facilitation of overall rate ranging from 4% to 14% with a median of 10%, and seven of nine subjects had higher running rates ranging from 3% to 19% with a median of 10%. All of the FR 99 sub-

Fig. 8. The time required to complete the separate parts of the FR 99 as a function of shock intensity. The first and final sets of points represent the pre-punished and post-punished performances. The letter "S" above the highest shock intensity in the graphs of some subjects indicates that complete suppression occurred under this intensity. Details of the figure are the same as for Fig. 7.

jects had a higher local rate in at least one of the three segments of the ratio. With both schedules, a facilitation of local rate in the shocked segment was present for 14 of the 17 subjects. This facilitation of shocked responses was weakest when the initial third of the ratio was punished, occurring with three of the six subjects and averaging 3%.

With both FR schedules and for all punishment conditions, the recovery of the FR performances was extremely rapid when the shock dependency was removed following complete suppression. In the first session in which an unpunished ratio was completed, six of the eight subjects under the FR 60 completed all scheduled ratios. The remaining subjects required one or two additional sessions. Most subjects immediately initiated a high rate of responding following completion of the first unpunished ratio. The overall and local response rates of the pre-punishment performances were approximated by each subject within six sessions after the session in which all scheduled ratios were completed. The particular features of each subject's FR performance reappeared, such as the variable running rate and occasional breaks during the ratio run by B-14. The only subjects showing a notable and stable difference between the pre-punishment and post-punishment FR performances were B-167 under the "Shock 1-20" condition and B-32 under the "Shock 21-40" condition whose post-punished performances exhibited shorter post-reinforcement pauses.

DISCUSSION

These results provide further evidence of the dependence of the temporal characteristics of punished FR behavior on the locus of the punishing stimulus within each ratio. All punishment conditions produced an increase in the average duration of post-reinforcement pauses with the extent of the increase related to locus of punishment, maximum when the initial third was punished and minimum when the final third was punished. The suppressing effect of punishment located in the first third of the ratio was focused on the initial stages of the ratio as seen by the extended post-reinforcement pauses and the limitation of suppressed responding to the first few responses in the ratio for most subjects. Disruption of the responding during the ratio became a gen-

eral and marked characteristic of the FR performances when the site of punishment was scheduled in the middle or final third of the ratio. A general finding from these two conditions was that punishment suppressed responses that preceded the punished segment and failed to suppress responses that followed the punished segment. This relation has been reported for selective punishment of chained FR performances (Holz, 1967), and punishment of a single response in the ratio (Dardano and Sauerbrunn, 1964b).

Another general finding was the relatively greater effect of punishment on the responses preceding the punished segment than on the responses being punished in the ratio with the smaller FR schedule, corroborating the results of Holz (1967). Whereas a marked disruption of the preceding unpunished responses was shown by all subjects under both "Shock 21-40" and "Shock 41-60" conditions, the disruption of punished responses in the ratio showed high inter-subject variability and was usually of small magnitude under "Shock 21-40"; no disruption of punished responses occurred under "Shock 41-60". Indeed, the rate of punished responses under "Shock 41-60" increased over the corresponding pre-shock rate when the unpunished responses of the ratio were suppressed. The greater suppression of responses preceding onset of punishment relative to the suppression of punished responses can be extended to the performances under both FR schedules if the restriction is added that the ratio includes an unpunished segment after the punished segment. The appropriate punishment locus would be the middle third of the ratio. All of the FR 99 subjects under this condition showed a markedly greater suppression of responses preceding the punished segment.

The size of the ratio was a factor in the type of effects produced by a punishment condition only when the final third of the ratio was punished. This punishment locus suppressed the punished responses in the ratio only with the FR 99 schedule. This result agrees with a related study reporting that an increase of shock intensity in successive thirds of an FR 100 produced a decrement in local rate during the final third of the ratio (Dardano and Sauerbrunn, 1964a). Since the same proportion of responses was punished in each ratio of the FR 60 and FR 99 schedules, fac-

tors relevant to the differential effect might include the greater number of responses punished in each ratio under the FR 99 schedule and/or the greater number of unpunished responses compared to the punished responses in each ratio of the FR 99.

The discussion of various suppressing effects of the punishment conditions should not obscure the extreme resistance of the FR performances to the disrupting influences of punishment. For most subjects, gross modifications of the FR performances were limited to the penultimate shock intensity tolerated by the subject, and a few subjects exhibited a clear suppressing effect only under the shock level that produced complete suppression. A further indication of the resistance to the suppressing effect of punishment was the consistent intra-session recovery of partially suppressed performance. A related point concerns the rapid recovery of the FR behavior from complete suppression when the punishment contingency was removed. Despite the extended exposure to the punishment contingency and repeated sessions in which intense punishment partially suppressed the behavior, such use of punishment did not permanently impair the FR performances.

Most of the main effects of the different punishment conditions on the FR performances can be interrelated by considering the punished performance as a several-member behavioral chain generated by the systematic relation between the punishing stimuli and the primary positive reinforcing stimulus. For example, punishing the middle third of the FR 60 would yield an FR 20 FR 20 punishment FR 20. The following interpretations consider response number within each link as a conditioned positive reinforcer and as a discriminative stimulus. Also, a gradient of the suppressing effect of punishment is assumed to extend from the initial punished response through the responses in the preceding member. Honig (1964, 1966) has reported a gradient of punishment effects on a stimulus continuum.

Within this framework, the possible control exerted by the punishing and positively reinforcing stimuli provide the following interpretations. (1) The lack of any suppressing effect of punishment on responses following the punished segment of the ratio would be ascribed to the absence of any aversive proper-

ties following the final punished response. (2) The relationship between the increased duration of post-reinforcement pauses and the locus of punishment can be referred to a gradient of aversiveness extending from the onset of punishment up to the stimuli present after food reinforcement. The conditioned aversiveness of these stimuli would be maximum when the initial third of the ratio was punished and would diminish in strength as the punishment locus was moved further into the ratio. (3) The disruption of responses preceding the punished segment could be related to such a gradient of conditioned aversive stimuli extending from onset of the punishing stimulus through the preceding segment. As responses accumulate in the unpunished segment, the increased strength of conditioned positive reinforcing stimuli would be accompanied by an increase in the strength of conditioned aversive stimuli. (4) A greater disruption of responses preceding the punished segment compared to the punished responses of the ratio can be related to an additional source of reinforcement acting on the punished responses. When the middle of the ratio is punished, the punished responses partly are controlled by the event defining the onset of the next member of the chain, namely, termination of the punishment condition. This event would negatively reinforce responding in the punished member. When the final third of the ratio is punished, the correlation of punishment with the primary reinforced member of the chain also could furnish the punishing stimulus with a positive reinforcing function.

The preceding analyses of some possible factors governing the nature of the responding during a ratio ignores sequential changes in the performance during a session. The effects of a punishment condition were not uniform during a session, even allowing for the consistent intra-session recoveries. In many instances, a grossly disrupted ratio was followed by a ratio that exhibited no impairment. This variability in the performance can partly result from the temporal irregularities of the scheduled events due to the inherent interaction of response rate with the schedule. For example, a high rate throughout a ratio produces a high shock rate that can momentarily change the effectiveness of the punishment condition in the following ratio.

REFERENCES

- Azrin, N. H. A technique for delivering shock to pigeons. *Journal of the Experimental Analysis of Behavior*, 1959, 2, 161-163. (a)
- Azrin, N. H. Punishment and recovery during fixed-ratio performance. *Journal of the Experimental Analysis of Behavior*, 1959, 2, 301-305. (b)
- Dardano, J. F. and Sauerbrunn, D. An aversive stimulus as a correlated block counter in FR performance. *Journal of the Experimental Analysis of Behavior*, 1964, 7, 37-43. (a)
- Dardano, J. F. and Sauerbrunn, D. Selective punishment of fixed-ratio performance. *Journal of the Experimental Analysis of Behavior*, 1964, 7, 225-260. (b)
- Ferster, C. B. and Skinner, B. F. *Schedules of reinforcement*. New York: Appleton-Century-Crofts, 1957.
- Holz, W. C. Punishing a portion of a behavioral sequence. Paper presented at the meeting of the American Psychological Association, 1967.
- Honig, W. K. and Slivka, R. M. Stimulus generalization of the effects of punishment. *Journal of the Experimental Analysis of Behavior*, 1964, 7, 21-25.
- Honig, W. K. The role of discrimination training in the generalization of punishment. *Journal of the Experimental Analysis of Behavior*, 1966, 9, 377-384.
- Lyon, D. O. Some notes on conditioned suppression and reinforcement schedules. *Journal of the Experimental Analysis of Behavior*, 1964, 7, 289-291.
- Rilling, M. E. Number of responses as a stimulus in fixed-interval and fixed-ratio schedules. *Journal of Comparative and Physiological Psychology*, 1967, 63, 60-65.
- Rilling, M. E. Effects of a timeout on a discrimination between fixed-ratio schedules. *Journal of the Experimental Analysis of Behavior*, 1968, 11, 129-132.

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