*SELECTIVE PUNISHMENT EARLY AND LATE
IN FIXED-RATIO SCHEDULES
OF FOOD REINFORCEMENT¹*

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Pigeons key pecked for grain on a fixed-ratio 100 schedule; electric shocks occurred intermittently at the fifteenth or eighty-fifth response in the ratio. In Experiment I, shock was at the fifteenth response for two birds, and at the eighty-fifth response for two others, in every sixth, twelfth, or eighteenth ratio. Rate of responding decreased as frequency of shock increased, and the pattern of responding included an increased initial pause and low rates or pause-run sequences that extended further into the ratio when shock was at the fifteenth response than when it was at the eighty-fifth response. Shock early in the ratio engendered longer initial pauses than shock late in the ratio. In Experiment II, four birds responded on a two-component multiple schedule in which shock occurred at the fifteenth response of the third ratio in the presence of a white keylight and at the eighty-fifth response of the third ratio in the presence of a green keylight. The overall rates of responding decreased as shock intensity increased. All four birds responded differentially to the white and green keylights, but with a pattern that varied between birds. In general, punishment reduced the probability of responses that preceded it, regardless of the ordinal position of those responses. Both studies confirm that the probability of responding is reduced less by aversive stimuli produced late in a fixed-ratio than by aversive stimuli produced early in a fixed-ratio.

Key words: punishment, selective punishment, multiple schedules, fixed-ratio schedules, key peck, pigeons

In schedules of selective punishment, electric shock is produced by a response or group of responses at a specific temporal or ordinal position in the pattern of responses generated by positive reinforcement. The effects of selective punishment procedures have been reported only for behavior maintained by fixed-ratio (FR) reinforcement schedules, *i.e.*, schedules that deliver the reinforcer following a fixed number of responses. Typically, FR reinforcement engenders bivalued responding, an initial pause before the first response followed by an abrupt change to a very high response rate that is notably resistant to modification (Azrin, 1959*b*; Lyon, 1964; Sidman and Stebbins, 1954). Selective punishment can prevent or delay the onset of the high terminal rate according to the

ordinal position of the punished response in the ratio. Dardano and Sauerbrunn (1964) shocked the first, twenty-fifth, or fiftieth response in an FR 50 reinforcement cycle. Punishment of the first response increased the initial pause. Punishment of the twenty-fifth or fiftieth response disrupted the FR pattern of responding with pause-run sequences, that is, repeated sequences of responding and not responding. Responses preceding shock were suppressed more than responses following shock in the reinforcement cycle. Further work by Dardano (1970) and Church (1969) confirmed that the pattern of responding generated by schedules of selective punishment varies with the ordinal position of the response correlated with shock.

Weisman and Davis (1975) maintained the pattern of responding engendered by a schedule of selective punishment without delivering the shock in every reinforcement cycle. With shock scheduled following the fiftieth response in only every ninth FR 100 reinforcement cycle (termed FR 9 *shock* by Weisman and Davis),

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a repeated pause-run pattern was observed, particularly early in the ratio.

The present two studies explored the differential suppression of FR responding produced by infrequent response-dependent electric shock delivered at an ordinal position early or late in the reinforcement cycle. A single response in an FR 100 occasionally produced shock. Early punishment occurred at the fifteenth response, and late punishment was at the eighty-fifth response. The choice of these two ordinal positions was made so that punishment would not occur until after responding had been initiated, and would not occur in too close temporal proximity with reinforcement. The occasional presentation of shock has the advantage of maintaining the repeated emission of patterns of responding generated by concurrent selective punishment and fixed-ratio reinforcement without dependence on any of the discriminative functions that might be attributed to shock delivered in each reinforcement cycle. Differential patterning with early and late punishment might then be attributed to an increasing response strength with decreasing ordinal distance from the reinforcer.

EXPERIMENT I

Experiment I made quantitative comparisons between the effects of shock dependent on responding at an ordinal position early, the fifteenth response, and late, the eighty-fifth response, in an FR 100 reinforcement schedule. The procedure departed from that of Dardano and Sauerbrunn (1964) and Weisman and Davis (1975), respectively, in that (a) neither the first nor the last response in the ratio was correlated with shock; (b) shock was presented in every sixth, twelfth, or eighteenth reinforcement cycle, *e.g.*, FR 6 shock, FR 12 shock, or FR 18 shock.

METHOD

Subjects

Four male Silver King pigeons, each 6 to 7 yr old, were maintained at approximately 80% of their free-feeding weights. The birds had no experimental histories.

Apparatus

Three operant conditioning chambers were used. One was of clear Plexiglas, 30 cm deep,

by 35 cm wide by 28 cm high; one wall was a three-key response panel, Grason-Stadler model H6446C. The other two chambers were Lehigh Valley models, 35 cm deep by 30 cm wide by 35 cm high, fitted with three-key response panels. In each chamber, the two side keys were removed and the openings blocked. The center key was mounted behind a 2.5-cm diameter aperture 24 cm above the floor and could be transilluminated with white light; 10 cm below the aperture was a 5-cm square opening that provided access to mixed grain. The white keylight was extinguished and a lamp over the feeder illuminated the grain during the 3.8-sec feeder cycle. A 6-W white houselight provided continuous general illumination while the session was in progress.

A 60-Hz electric shock, 0.2 sec in duration, was delivered through a 10 K-ohm fixed resistance in series with the bird. The output of the shocker was normally shorted across the leads to the bird, and the bird was switched into the circuit when shock was delivered via stainless-steel wire electrodes, 0.6 mm in diameter, chronically implanted through the bird's pubic arch (Azrin, 1959a). Electrical impedance across the electrodes of each bird was measured by a 7-V, 60-Hz bridge circuit and ranged from 0.8 to 1.2 K-ohms.

The pigeon chambers were enclosed in a sound-attenuating compartment ventilated by an exhaust fan. White noise served to mask most extraneous sounds. Scheduling and recording equipment were located in a separate room.

Procedure

Each daily session terminated after 2 hr or approximately 36 reinforcements, whichever occurred first. The weight and electrode impedance of each bird were determined before and after each session. Postsession feeding adjusted the birds' weights upward as required and electrodes were cleaned at least once weekly.

After initial shaping of the key-peck response and gradual increases in the number of responses preceding the reinforcer, each bird had extensive training with the FR 100 reinforcement schedule. Shock was introduced, in every second reinforcement cycle, following the fifteenth response for Birds 4805 and 4503 and following the eighty-fifth response for Birds 6266 and 3242. Shock intensities resulting in

Table 1

The sequence of schedules and number of sessions in Experiment I.

	Fifteenth Response		Eighty-fifth Response	
	Bird: 4805	4503	6266	3242
No shock	38	42	39	41
FR 12 shock	29	32	35	30
FR 18 shock	26	27	30	24
FR 6 shock	27	34	22	27

extensive, but not complete, response suppression, were used throughout the experiment proper: 6 mA for Bird 4805, 11 mA for Bird 4503, 9 mA for Bird 6266, and 12.5 mA for Bird 3242. In these subsequent sessions, shock followed either the fifteenth or the eighty-fifth response according to fixed-ratio schedules, in turn, FR 12 shock, FR 18 shock, and FR 6 shock. The numbers of sessions without shock and at each fixed-ratio shock schedule are shown in Table 1. The shock schedule was changed only when the overall rate of responding exhibited no obvious trends from day to day, over at least four consecutive sessions.

RESULTS

Typical fixed-ratio performance was observed in all birds before shock was introduced. The cumulative response records of Birds 4503 and 3242, shown in Figure 1, provide some evidence that suppression of responding depended on whether the fifteenth or the eighty-fifth response was correlated with electric shock. In the former instance, the pause-run sequences continued over the early portion of the ratio but were not necessarily confined by the fifteenth response. In the latter instance, the pause-run sequences sometimes continued over a larger portion of the ratio but were confined by the eighty-fifth response. Records for Bird 4503 occasionally show a disrupted pattern of responding past the fifteenth response into the middle of the ratio; records for Bird 3242 show many ratios in which responding was relatively undisturbed and the high terminal rate was begun well before the eighty-fifth response. However, even at FR 18 shock these cumulative records show systematic effects of the ordinal response that produced shock. Records for Birds 4805 and 6266 were comparable with

Fig. 1. Cumulative response records of typical performance with each schedule in Experiment I. Shocks at the fifteenth response are shown as deflections of the response pen; shocks at the eighty-fifth response are shown by the event pen; the response pen reset after each reinforcement.

Fig. 2. Distributions of the initial pause. Inverted triangles mark the median of each distribution.

those shown for Birds 4503 and 3242 respectively.

Distributions of the initial pause in the reinforcement cycle are shown in Figure 2. An inverted triangle marks the median of each distribution in this figure and in Figures 3 and 4. Initial pauses were longer with FR 6 shock than with less frequent shock, but FR 12 shock

did not necessarily increase the initial pause over FR 18 shock. Pause lengths were considerably more variable at all three shock schedules than they were in the no-shock conditions. Shock early in the FR 100 reinforcement cycle generated more long initial pauses than shock late in the ratio.

Distributions of the rate of responding before and after the response at the ordinal position correlated with shock in each reinforcement cycle are shown in Figures 3 and 4 respectively. In general, increasing shock density increased the incidence of low response rates before the response at the ordinal position correlated with shock; after that response, rates of responding were higher than those before it. Both distributions differentiate the ordinal position of shock somewhat. Shock at the fifteenth response resulted in lower prior rates than shock at the eighty-fifth response. With increasing shock density, low subsequent rates were more frequent when shock was at the fifteenth response than when shock was at the eighty-fifth response.

EXPERIMENT II

In Experiment I, if the response intermittently correlated with electric shock occupied an ordinal position late in the FR reinforcement cycle, then the initial pause tended to be shorter and rates of responding higher than if the punished response occurred earlier in the ratio. However, the pause-run sequences engendered by these schedules frequently continued beyond the early ordinal position correlated with shock. Thus, while patterns of responding similar to those reported by Dardano and Sauerbrunn (1964) were observed, differentiation between the effects of response-dependent shock early and late in the ratio appeared to be less pronounced in Experiment I.

Experiment II compared the rates and patterns of responding generated by correlating shock with responses at ordinal positions either early or late in the FR reinforcement cycle for individual birds within experimental sessions. Accordingly, the two selective punishment procedures studied in different birds and between sessions in Experiment I became the components of a multiple schedule introduced in Experiment II, but with shock intensity as an independent variable rather than shock den-

Fig. 3. Distributions of response rate before the response correlated with shock. Inverted triangles mark the median of each distribution.

sity. Multiple schedules alternate two or more component schedules each of which is associated with a different discriminative stimulus during the experimental session. Specifically, Experiment II studied performance as a function of the intensity of electric shock intermittently produced by the fifteenth and the eighty-fifth responses of an FR 100 reinforcement schedule in separate components of a multiple schedule.

Fig. 4. Distributions of response rate subsequent to the response correlated with shock. Inverted triangles mark the median of each distribution.

METHOD

Subjects

Four male Silver King pigeons, each 6 to 7 yr old, were maintained at approximately 80% of their free-feeding weights. Birds 3251, 4576, and 6772 had previous training with schedules

that correlated the fiftieth response in FR 100 with shock; Bird 3242 had training with schedules that correlated the eighty-fifth response in FR 100 with shock in Experiment I.

Apparatus

The apparatus was the same as in Experiment I.

Procedure

For Birds 4576 and 3251, each session terminated after 2 hr or 36 reinforcements, whichever occurred first; for Birds 6772 and 3242, the same time limit or only 30 reinforcements ended each session. The weight and electrode impedance of each bird were measured and adjusted as in Experiment I.

Key pecks were reinforced according to an FR 100 schedule in each component of the multiple schedule. The keylight color alternated between white and green following every third reinforcement. The two components correlated electric shock with the fifteenth response in every third fixed ratio emitted in the presence of the white keylight (W) and with the eighty-fifth response in every third fixed ratio emitted in the presence of the green keylight (G). Sessions began equally often with each component.

Several sessions without shock preceded its introduction. The intensity of electric shock was increased in 2-mA steps, and the transition from one step to the next was accomplished by gradually increasing shock intensity over three to four sessions. These transitions were begun after at least 12 sessions at the prior 2-mA step, but were postponed for up to 10 sessions if the rate of responding was systematically increasing or decreasing over the preceding four days. Shocks were discontinued when responding was so suppressed that no more than two ratios were completed in a session for at least three consecutive sessions. Table 2 shows the number of sessions at 0 mA, at each 2-mA step, and again at 0 mA for each bird.

RESULTS

Figure 5 shows the average rates of responding in the presence of the white and green keylights (marked W and G in the figure), the discriminative stimuli associated, respectively, with electric shock at the fifteenth and eighty-fifth responses in separate FR components of the multiple schedule, for the final six sessions

Table 2

The number of sessions at each shock intensity in Experiment II.

Shock Intensity	Bird:	Number of Sessions			
		4576	3251	3242	6772
0 mA		18	18	17	18
2 mA		15	15	15	15
4 mA		21	21	21	18
6 mA		21	16	18	16
8 mA		9	24	22	15
10 mA		—	12	12	12
12 mA		—	—	—	12
14 mA		—	—	—	29
0 mA		30	29	28	40

at 0 mA and for the last six sessions at each 2-mA shock intensity increase that supported a nonzero rate of responding. The replication of the 0-mA condition is shown as a separate point offset from the initial determination of that point. Occasionally at higher shock intensities, fewer than 300 responses per session were emitted. In these sessions, only one stimulus or the other prevailed; as a result, no measure of response rate to the other stimulus was available. The average rate of responding to each stimulus was calculated from only those sessions in which that stimulus was presented.

For all birds, the overall rates of responding were reduced as a function of the increasing shock intensity. Birds 4576, 3251, and 3242 responded at a considerably lower rate to the white than to the green keylight at shock intensities higher than 2 mA. These birds responded little if at all to the white keylight at intensities of 6 to 8 mA or greater; when the keylight was green, with one minor exception, responding decreased more slowly as a function of increasing shock intensity. For Bird 6772, the average rates of responding to the two keylight colors were not clearly differentiated in two components as a function of shock intensity. After shock was terminated, all birds recovered a rate of responding close to that emitted before shock.

Figure 6 shows cumulative response records for Birds 3251 and 6772 at each shock intensity except the most extreme. For each intensity, one record of a session beginning with the white keylight and one beginning with the green keylight is shown. Deflections of the response pen show the responses that were correlated with shock. The keylight was white when the event pen was down, and green when the

Fig. 5. Rates of responding to the white and green keylights, the stimuli associated with response-dependent shock delivered early and late in the fixed-ratio reinforcement cycle, respectively, for Birds 4576, 3251, 3242, and 6772, averaged over the final sessions at each shock intensity. The second determination of the point at 0 mA is offset to the left.

pen was up. Records for Bird 3251 also show performance typical for Birds 4576 and 3242. The record of responding for Bird 3251 at 6 mA reveals three sources of lower average rates of responding to the white keylight: (a) the initial pause in the first ratio of a component was much longer; (b) subsequent initial pauses in a component were in general longer; (c) responding early in the ratio was often disrupted when the keylight was white, but responding was only rarely disrupted at any ordinal position in the ratio when the keylight was green. Records of performance at 8 mA show an important consequence of long initial pauses when the keylight was white: the next component, with the green keylight, was often omitted when shock was intense and the session began with the white keylight. Thus, the first component of the session seemed especially sensitive to the effects of the ordinal position of shock on the initial pause, particularly at the higher shock intensities.

Although average rates of responding to both keylight colors were often similar for Bird 6772 (see Figure 5), cumulative response records for this bird (see Figure 6) showed that the white and green keylights controlled very different patterns of responding. Patterns of responding to green differed strikingly from those obtained from the other birds. Responding was disrupted by repeated pause-run sequences of responding and not responding before the ordinal position correlated with shock. However, patterns of responding to white were similar to those of the other birds, except that initial pauses in the first ratio were

no longer, and often shorter, than in the succeeding two ratios of the component.

A summary analysis of the patterns of responding engendered by white and green keylights is shown for each bird in Figure 7. These averaged cumulative response records were derived from the mean time between every fifth response in each of the six ratios that comprised a cycle of the multiple schedule. Each averaged ratio in Figure 7 represents the average of at least 15 like ratios taken from the last four sessions at 0 mA and at the penultimate intensity. Time and response scales are in proportion to those of individual cumulative response records. Even though the pause-run sequences observed in so many individual ratios were smoothed in the averaging process, these records confirm that analyses based on individual cumulative response records for Bird 3251 apply for Birds 4576 and 3242 as well. Comparison of shock with no shock (0 mA) suggests that response rates after initial pausing were slightly reduced when the keylight was green, but responding was more precisely controlled by shock correlated with an ordinal position early in the ratio, than by shock correlated with an ordinal position late in the ratio. It is also evident that the two components of the multiple schedule of selective punishment controlled differential responding for each bird.

GENERAL DISCUSSION

In both experiments, the patterns of responding in the fixed-ratio reinforcement cy-

Fig. 6. Cumulative response records of typical performance in each component of the multiple schedule in sessions beginning with the white (W) and green (G) keylights in Experiment II. Shocks are shown as deflections of the response pen.

Fig. 7. Cumulated responding averaged in five-response blocks over several instances of each of the six fixed ratios in a cycle of the multiple schedule. These records have the same relative proportions as those drawn by a cumulative recorder. The identification of schedule components, shocks, and reinforcements is the same as in Figure 6.

cles were differentially affected according to the ordinal position of the response correlated with occasional shock. Experiment II confirmed the findings of Experiment I, that in general, shock early in the ratio produced a lengthened initial pause and low rates of responding in the early part of the ratio, while shock late in the ratio produced low rates of responding that extended further into the ratio, and less increase in the initial pause. This confirmation increases the likelihood that the difference between the small groups in Experiment I was due to systematic factors and reduces the likelihood that they were due to individual differences between the birds.

That differential effects of schedules of selective punishment were observed when shock was delivered infrequently also bears importantly on two unsettled issues, first raised by Dardano

and Sauerbrunn (1964) and Weisman and Davis (1975). When shock was scheduled in every reinforcement cycle (Dardano and Sauerbrunn, 1964) the role of shock as a discriminative stimulus for reinforcement without further shock seemed difficult to discount. Shock was absent from most reinforcement cycles in the present study, yet patterns of responding similar to those reported by Dardano and Sauerbrunn were obtained. Thus, the role of shock as an effective discriminative stimulus for food in the context of schedules of selective punishment must be seriously questioned. Weisman and Davis (1975) noted that punishment of FR performance reduced the rate of reinforcement and therefore might have affected the rate and pattern of responding only indirectly. This suggestion can be shown to be unlikely by results available from Experiments

I and II of the present report. In Experiment I, Birds 4805 and 3242 had nearly equal rates of reinforcement at FR 12 shock and FR 6 shock respectively, but different patterns of responding were controlled by the two schedules of selective punishment. In Experiment II, Bird 6772 had nearly equal rates of reinforcement in the presence of the two keylight colors, but again different patterns of responding were controlled by the two schedules of selective punishment.

Two studies have examined the effects of nonselective presentation of aversive stimuli on fixed-ratio performance. Dardano (1972) varied the ordinal position of the response correlated with shock randomly from one fixed-ratio reinforcement cycle to the next, but found responding more severely disrupted early than late in the fixed ratio. When Lyon (1964) presented a Pavlovian conditioned stimulus (CS) for shock independently of responding, complete suppression in the presence of the CS was observed only when the CS had its onset early in the fixed ratio. It would appear that the effectiveness of an aversive event in suppressing responding varies inversely with the ordinal proximity of responding to reinforcement. In the sense recently suggested by Nevin (1974), response strength is greatest late in the fixed ratio and least early in the fixed ratio.

The different patterns of responding engendered by the selective punishment schedules used by Dardano and Sauerbrunn (1964), Weisman and Davis (1975), and in the present experiments may reflect differing resistances to the suppression that results from response-dependent shock at positions near or distant from reinforcement. Thus, the initial pause and responding early in the ratio are differentially suppressed by response-dependent shock early in the ratio not only because they immediately precede the punishment operation, but also because they occur at a considerable ordinal distance from the reinforcement operations. Conversely, performance late in the ratio is less easily disrupted by response-dependent shock, even when the performance immediately precedes the punishment operation, because it is emitted ordinally proximal to the reinforcement operation.

In both of the present experiments, the most reliable effects of shock delivered either early or late in the reinforcement cycle were those

obtained early in the ratio, e.g., increased initial pause times. Discriminative control of pause time and subsequent responding, in Experiment II, left little doubt that these patterns of responding were dependent on the specific punishment contingency associated with each of the two alternating discriminative stimuli. However, alternation of the two procedures as components did not necessarily increase the difference between resulting patterns of responding. Comparison of performance for Bird 3242 in Experiments I and II (Figures 1 and 6) finds the disruption of responding engendered by shock at the eighty-fifth response reduced by the alternation with shock at the fifteenth response. The effect was to make responding to the green keylight more like that to the white keylight. Perhaps changes in the opposite direction are opposed by the resistance of responding late in the ratio to suppression.

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