CHAINED AND TANDEM FIXED-INTERVAL SCHEDULES OF PUNISHMENT¹

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Pigeons' key pecks were both punished with electric shock on four-component chained and tandem fixed-interval schedules and reinforced on a variable-interval schedule of food presentation. Pecking was suppressed less in the early components of the chained schedule than in the early components of the tandem schedule. Related multiple and mixed schedules of punishment were also presented; these schedules were identical to the chained and tandem schedules, respectively, except that components changed independently of responding. Similar effects were obtained, in that responding was suppressed in all components of the mixed schedule and only in the fourth component of the multiple schedule of punishment. The performances maintained on the chained and tandem schedules of punishment were generally symmetrical to those found in analogous chained and tandem schedules of food reinforcement.

In studies of extended chained schedules of reinforcement, it has been found that responding is not easily maintained in the initial components (Gollub, 1958; Kelleher and Fry, 1962). Gollub (1958), for example, found that in a chained schedule composed of five fixed-interval 1-min (FI 1-min) components, each associated with a different stimulus, pauses of more than 1 hr developed in the first component. In the comparable tandem schedule, in which the same stimulus was associated with all components, pauses of only 6 or 7 min occurred in the first two components, and the others were completed in about 1 min each. Kelleher and Fry (1962), comparing three-component chained and tandem FI schedules, suggested that each stimulus in the chain becomes a discriminative stimulus for a particu-

lar consequence and controls a corresponding rate of responding.

The present experiment involved chained schedules of punishment. By analogy to chained schedules terminating in food presentation, a chained schedule of punishment is one in which the delivery of a punisher depends on the sequential completion of two or more component schedules, each in the presence of a different stimulus. The schedule of punishment examined was a four-component chain of FI 30-sec components; the first response after the completion of four 30-sec fixed intervals was followed by electric shock. A response was required at the end of each fixed interval to start the next one and to change the component stimulus. Responding was maintained on a variable-interval schedule of positive reinforcement that was in effect during all components.

The stimulus correlated with the terminal component is one in whose presence responding is punished. Presumably this stimulus could become a conditioned aversive stimulus, and its occurrence punish responding that produces it. Thus, one might expect suppression of responding during the third component of the four-component chained schedule of punishment. To the extent that each of the stimuli in the chain becomes a conditioned punisher there should be suppression of the responding that precedes its delivery. By anal-

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ogy to the extended chained schedules of reinforcement described above, however, one might predict the absence of conditioned punishing effects on responding in the initial components of chained schedules of punishment.

In addition to chained schedules of punishment, the experiment included tandem schedules, and related multiple and mixed schedules of punishment. The multiple and mixed schedules of punishment were similar to the chained and tandem schedules respectively, except that components changed automatically in the multiple and mixed schedules, while a response changed the components in the chained and tandem schedules. The multiple and mixed schedules thus served as control procedures for the response-dependent component change of the chained and tandem schedules. Each of these four conditions was presented both with shock in the last component and with no shock, so that the degree of suppression produced by the presentation of shock could be directly assessed.

METHOD

Subjects

Four adult male White Carneaux pigeons were maintained at approximately 80% of their free-feeding body weights. Three (220, 221, and 223) had previously been trained to key peck under continuous and variable-ratio schedules of reinforcement. The fourth (42), had served in several experiments, including one involving color and line-orientation discriminations and another involving schedules of punishment.

Apparatus

The experimental area was a standard pigeon chamber, 12 by 14 by 13 in. high (30.5 by 35.6 by 33.0 cm), enclosed within a sound-attenuating compartment. A single Gerbrands response key mounted 8.5 in. (21.6 cm) above the floor was operated by approximately 0.147 N of force. Each operation of the key produced an audible click of a dc relay. A Grason-Stadler multiple stimulus projector transilluminated the key with red, green, blue, or white light, as well as with three vertical white lines on a dark background. The reinforcer consisted of 2.5-sec access to mixed grain in a standard feeder, located 5 in. (12.7 cm) center to center

below the key. During food presentation the key was not illuminated.

Electric shock (117 v 60 Hz) was delivered through stainless steel wires (18/8 stainless 0.06 cm) implanted around each pigeon's pubis bones; a harness-and-pulley arrangement allowed the pigeon relatively unconstrained movement around the chamber (Azrin, 1959). The shock circuit was similar to one described by Ramsay, Knapp, and Zeiss (1970). An ammeter wired in series with the pigeon continually monitored the amount of current passing through the pigeon; the range of 0 to 10.0 mA was controlled by a series of fixed and variable resistors. Five minutes before the start of each experimental session in which shock was to be delivered, a given level of shock was measured directly across the pigeon and calibrated by means of a variable resistor. Shock duration, which was 0.5 sec, was controlled by an electronic timer. Standard scheduling and recording equipment was used (Ferster and Skinner, 1957).

Procedure

Key pecking was maintained on a variable-interval schedule of reinforcement under the stimulus conditions described below. The interval between the end of one food presentation and the availability of the next was 60 sec on the average (VI 60-sec). The probability of reinforcement as a function of time since the last reinforcement was approximately constant, according to specifications suggested by Catania and Reynolds (1968, Appendix II). In all of the following procedures this schedule was continuously in effect whenever the response key was illuminated.

Chained and Tandem Schedules of Punishment

In each cycle, the key was illuminated during four 30-sec consecutive components, ending in a response-produced electric shock (punishment). During the chained schedules, the key was lit with a different color during each component; the order of colors was red, green, white, and blue. During the tandem schedule, the vertical-line stimulus remained on the key during all four components. The first response after 30 sec in each component started the timer for the next component. The first response after 30 sec in the terminal (fourth) component of both the chained and tandem

schedules produced a 0.5-sec electric shock, which was followed by a 30-sec timeout (key dark) during which responses had no scheduled consequences, and then the start of the next cycle. The schedules of punishment were chain and tandem FR 4 (FI 30-sec), concurrent with a VI 60-sec reinforcement baseline.

At the end of the terminal component, the key remained lit until the punished response occurred, or until 30 sec more had passed (30-sec limited hold), whichever came sooner. Thus, if the pigeon did not respond for 30 sec after the end of the fourth component, no shock was delivered before the timeout and the start of the next cycle. There was no limited hold at the end of each of the first three components, however; only a key peck could initiate the next component.

In each daily session chained and tandem cycles alternated, with timeouts between. The session ended after 30 cycles (15 chain, 15 tandem) or after 2 hr, whichever came sooner. When a session had continued for 2 hr, and 30 cycles were not yet completed, the session was terminated at the end of the component in progress.

To establish a base level from which the effects of punishment could be assessed, these schedules were first presented for several weeks with no shock at the end of each cycle. Shock was then introduced as specified above at a level of 2.0 mA for five sessions. Succeeding groups of at least five sessions each were given with shock levels of 4.0, 6.0, and 8.0 mA. The upper part of Table 1 shows the order and number of sessions at each shock intensity.

In these punishment sessions, as well as in the multiple and mixed procedures described below, the punished response was never rein-

forced, even if reinforcement was scheduled. This precaution was taken to prevent the pairing of food and shock, which might establish shock as a conditioned reinforcer. A further restriction was that a reinforcement scheduled for one cycle but not occurring in that cycle was cancelled before the next cycle began. This prevented a spuriously high probability of reinforcement for the first peck of a cycle after pausing in the fourth component of the previous cycle.

Multiple and Mixed Schedules of Punishment

The multiple and mixed procedures were the same as the chained and tandem procedures respectively, except that the first three components of each cycle now ended automatically after 30 sec; no response was required to start the successive components. In the multiple schedule, the stimulus color changed every 30 sec; the order of stimuli was red, green, white, and blue, as in the chained schedule. In the mixed schedule, the vertical lines remained on the key during all four components. At the end of the terminal component of both schedules a response produced a 0.5-sec shock. A limited hold was again in effect; if, at the end of the fourth component no response occurred for 30 sec longer, there was no shock before the timeout and the start of the next cycle. Since responding in the first three components of these schedules had no relation to the delivery of shock, the schedules of punishment were *mult* EXT EXT EXT FI 30-sec and *mix* EXT EXT EXT FI 30-sec, both on a VI 60-sec reinforcement baseline. Although these two schedules were analyzed as multiple and mixed schedules of punishment for purposes of comparison with the chained and tandem schedules, they were identical to FI 2-min schedules of punishment. Since the stimulus changed every 30 sec in the multiple schedule, it was, by analogy to schedules of food presentation, an FI 2-min schedule of punishment with a discrete, or block, clock added (Segal, 1962).

Multiple and mixed cycles alternated throughout each 30-cycle session, and each cycle was followed by a 30-sec timeout. Again, a no-punishment baseline was first established and then a number of sessions at different shock intensities were run (lower part of Table 1).

Table 1

Sequence of procedures and number of sessions in each procedure.

<i>Schedule</i>	<i>Shock Intensity (mA)</i>	<i>Number of Sessions</i>
Chain-Tandem	0 (baseline)	22
	2	5
	4	8
	6	9
	8	7
Multiple-Mixed	0 (baseline)	7
	2	7
	4	7
	6	7
	8	7

RESULTS

Chained and Tandem Schedules

Figure 1 shows each pigeon's response rate in the four components of the chained and tandem schedules, both with and without punishment in the terminal component. Rates are medians of the last five sessions of a given condition. The solid lines are the no-shock baselines. On the chained schedule baseline, three of the pigeons (42, 221, and 223) had higher rates in the fourth component than in the first three components; original key-peck training had been carried out with a blue key-light, which was also the stimulus during the fourth component. On the tandem baseline, two of the pigeons (42 and 221) had a decreasing rate from the first through the fourth component. Otherwise, baseline rates did not differ consistently from component to component.

The punishment curves (dashed lines) in Fig. 1 correspond to the lowest shock intensity

at which each pigeon showed clear suppression effects. This value was selected by determining the average duration of each component in the last five sessions at each intensity of shock; the intensity at which the median of these five average durations exceeded 35 sec for any component was considered to be the threshold for the suppressive effects of shock. Although these values were different for different pigeons, a given intensity produced suppression in both chained and tandem schedules for each of the pigeons, except Pigeon 42. For this pigeon, there was suppression on the chained schedule at 4 mA and on the tandem at 6 mA.

On the chained schedule of punishment (upper panel of Fig. 1), in which each component was correlated with a different stimulus and in which the last response of the terminal component was punished, rates were high and relatively constant in the first three components and low in the fourth. Compared with the baseline, there was a decrement

Fig. 1. Response rates on the chained (upper panel) and tandem (lower panel) punishment schedules for each pigeon in each of the four components. Rates shown are medians of the last five sessions in that condition. Solid lines are no-shock baselines; dashed lines are for punishment sessions at the shock intensity indicated. The selected intensities are those at which median average duration of any component exceeded 35 sec.

of at least 70% in the fourth component and little difference in the first three components for three of the pigeons (42, 221, and 223). There was suppression relative to the baseline in the third component as well, most notable for pigeon 223, but this decrement was small compared to that in the fourth component.

The shape of the chain punishment curve for Pigeon 220 is similar to that for the other three pigeons: high and constant rates in the first three components and a low rate in the fourth. However, when compared with the baseline, rates under the punishment schedule approximately doubled in the first three components and remained unchanged in the fourth. This pigeon's limited experimental history before the present study is reflected in its low baseline rates; the increase in the punishment curve may be due in part to an increasing overall rate during the course of the experiment.

The tandem punishment procedure, in which a single stimulus was present during all four components and in which the last response of the terminal component was punished, produced similar results for Pigeons 42, 221, and 223 (lower panel of Fig. 1); there was suppression in all four components relative to the baseline, and rates were successively lower in the first through last components. Pigeon 220, again different from the others, showed suppression in the first two components and no effect in the last two.

Table 2 shows median rates and ranges in the four components of the chained and tandem punishment schedules at each shock intensity. Rates were based on the actual durations of the components, rather than on the 30-sec minimum duration. The rows marked with asterisks are those plotted in Fig. 1. At intensities lower than those plotted in Fig. 1 rates were unchanged from baselines except for overall increases for some pigeons. At intensities higher than those in the figure, rates were further suppressed in the third (Pigeons 42 and 223) and fourth (Pigeons 42, 221, and 223) components of the chained schedule and in all components of the tandem. The lower limits of the ranges show that in occasional sessions at higher intensities responding was severely disrupted.

Cumulative records illustrating chained and tandem punishment performances are shown in Fig. 2. The tandem cycles are under-

lined. The top record is from a baseline session for Pigeon 42. The rate was fairly constant from one component to the next, although occasionally the rate in the last component of the chain was noticeably higher than that in the other components, as at *a* (cf. Fig. 1). The occasional pauses in the response record were during food presentation, when the recorder motor continued to operate. Throughout the baseline session, overall rate on the chained schedule was higher than rate on the tandem.

The middle record is from a chained and tandem session with 6 mA shock, also for Pigeon 42. In several of the chain cycles, as at *b*, and *d*, rate was high in the first three components and close to zero in the fourth. At *e*, the rate also decreased in the third component, and was again zero in the fourth. In each of these chain cycles (*b*, *d*, and *e*) the pigeon paused for 30 sec at the end of the fourth component and no shock was delivered. In several of the tandem cycles, as at *c* and *f*, rate was high in the first component and decreased in each successive component, although the pigeon did not pause long enough in the terminal component to avoid the shock. In some of the tandem cycles there were long pauses, which occurred in the early components, after a shock had been delivered in the preceding chain cycle, as in the tandem cycle following *g*.

A slightly different performance at 6 mA is shown in the bottom record, which is for Pigeon 223. In several of the chain cycles, this pigeon responded at a high rate during the first three components and part of the fourth, and then abruptly stopped for the remainder of the cycle, as at *i*. In other chain cycles, rate decreased in the third component (*j*), and in still others, in the second component (*h*). In most of the tandem cycles, rate was low and decreased with successive components.

Multiple and Mixed Schedules

Figure 3 shows response rates for each pigeon in each component of the multiple and mixed punishment schedules with no shock and at a selected shock intensity. The no-shock baselines (solid lines) of the multiple and mixed schedules were similar to those of the chained and tandem schedules respectively (cf. Fig. 1). Rates were high in the last component of the multiple schedule for Pigeon 42;

Table 2

Rates (responses per minute) in the four components of the chained and tandem punishment schedules for each shock intensity. Rates shown are medians and ranges of the last five sessions in each condition. For each pigeon, the baseline and the intensity marked with an asterisk are those plotted in Fig. 1.

Pigeon	Intensity (mA)	Chain				Intensity (mA)	Tandem			
		1	2	3	4		1	2	3	4
42	0	90 63-101	79 70-109	87 67-95	115 63-139	0	97 64-103	85 63-90	83 57-90	84 58-93
	2	114 73-129	92 81-96	93 81-101	114 102-124	2	98 78-100	86 75-88	81 75-89	78 77-89
	4*	96 73-104	88 79-99	76 74-83	5 2-24	4	92 53-125	84 70-118	80 63-115	82 74-106
	6	72 58-100	70 37-82	25 19-59	0 0-3	6*	31 3-55	21 4-38	13 1-24	14 4-25
	8	77 35-102	87 41-99	18 11-71	1 0-2	8	2 0-28	1 0-10	2 0-4	1 0-9
220	0	44 35-55	32 22-39	38 25-49	35 26-43	0	36 26-50	36 18-53	36 16-49	30 14-43
	2	56 32-66	48 43-53	47 42-50	40 38-42	2	42 32-47	38 31-44	36 31-42	32 25-39
	4	38 36-54	37 33-43	39 37-40	44 37-52	4	32 28-37	35 33-46	31 29-38	27 24-37
	6	49 14-64	44 33-64	50 28-59	44 26-62	6	34 4-46	41 7-43	38 8-49	32 12-44
	8*	74 5-89	70 2-87	69 2-92	33 1-38	8*	6 1-70	12 2-40	39 4-59	32 9-54
221	0	79 58-91	108 95-125	100 85-114	112 103-115	0	103 85-112	89 80-100	83 70-90	74 73-86
	2	85 63-101	97 95-121	98 96-121	99 96-118	2	102 97-113	87 87-95	84 82-100	82 80-89
	4	89 74-94	118 94-124	112 87-125	103 77-111	4	96 87-110	82 77-93	85 68-88	81 68-88
	6*	82 29-95	97 62-107	86 58-89	22 14-33	6*	51 35-66	33 21-64	14 8-57	11 7-53
	8	95 28-103	104 17-123	98 19-111	18 5-24	8	38 27-82	23 10-48	8 4-24	5 3-13
223	0	88 82-97	79 76-86	88 85-91	123 108-128	0	88 84-100	93 81-102	91 79-96	88 84-97
	2	85 62-118	94 64-115	109 66-110	89 36-105	2	91 55-110	88 47-97	84 40-89	76 49-87
	4*	82 46-87	75 49-80	63 27-69	3 0-7	4*	14 1-24	8 1-13	5 2-12	3 1-10
	6	59 23-69	49 39-74	39 23-72	3 2-15	6	2 1-12	1 1-12	1 0-3	2 1-10
	8	54 35-87	46 38-79	69 23-85	8 1-15	8	8 0-44	9 1-35	9 1-24	6 1-11

rates declined across components of the mixed schedule for Pigeons 42 and 221.

The punishment curves (dashed lines) correspond to the lowest shock intensity for each pigeon at which the median average duration of the fourth component was greater than 35 sec. Only the fourth component was consid-

ered since the duration of each of the first three components was always 30 sec. On the multiple punishment schedule (upper panel), rates for Pigeons 42, 221, and 223 were close to those of the baseline in the first three components and greatly suppressed in the fourth. Rates of Pigeon 220 were suppressed in all but

Fig. 2. Sample cumulative records from the chained-and-tandem punishment sessions. The tandem cycles are underlined. The response pen reset at the end of each chain or tandem cycle. The flat section after reset indicates the timeout between cycles. There is a diagonal pip at the end of the timeout and at the end of each of the first three components; there is also a pip after 30 sec in the fourth component. If the cycle ended with a shock there is no pip before reset; if the limited hold ended the cycle there is a pip before reset. Food presentations are not indicated in the record. The top record is from a baseline session. The middle and lower records are from sessions with 6 mA shock.

the second component, but suppression was greatest in the fourth.

The effect of punishment in the mixed schedule (lower panel) was an overall suppression of rate with decreasing rates from first through fourth components. This latter effect is least clear for Pigeon 220 whose baseline was lower than those of the other pigeons.

Table 3 shows median rates and ranges in the four components of the multiple and mixed punishment schedules at each shock intensity. The rows marked with asterisks are those plotted in Fig. 3. Generally, at intensities higher than those plotted in Fig. 3, suppression increased as a function of intensity. The occasional disruption of responding by shock at high intensities can be seen from the lower limits of the ranges. There are no data

given for Pigeon 220 at 6 mA because one of the stainless steel electrodes was out and no shock was delivered. The almost total suppression at 8 mA for this pigeon may be due to the sudden reintroduction of shock at such a high level after seven sessions without shock (*cf.* Miller, 1960).

In Fig. 4 are sample cumulative records from multiple and mixed punishment sessions. The mixed cycles are underlined. The upper record is from a no-shock baseline session for Pigeon 42. Rates were high and relatively constant from component to component. The occasional pauses in the response record are during food presentations, when the motor continued to operate. The middle record is for Pigeon 42 at 8 mA. In the multiple cycles, the pigeon responded at a high rate in the

Fig. 3. Response rates on the multiple (upper panel) and mixed (lower panel) punishment schedules for each pigeon in each of the four components. Rates shown are medians of the last five sessions in that condition. Solid lines are no-shock baselines; dashed lines are for punishment sessions at the intensity indicated. The selected intensities are those at which median average duration of the fourth component exceeded 35 sec.

first three components and often in the first part of the fourth, and then stopped for the remainder of the cycle, as at *c* and *g*. Occasionally, the pigeon did not stop soon enough, and received a shock, as at *b*. In the mixed cycles, Pigeon 42 most often responded at a high rate in the first components and gradually slowed down, as at *d* and *f*. Occasionally, the pigeon responded at a very low rate in all four components of the mixed cycle (*a*) or at a high rate in all four components (*e*).

The lower record in Fig. 4 is from a session at 6 mA for Pigeon 223. The performance is similar to that in the middle record. Rates on the multiple schedule were generally high in the first three components and zero in the fourth. Toward the end of the session, rates also decreased in the third component of the multiple cycles, as at *k* and *l*. On the mixed schedule, rates were high during the first one or two components and then low, as at *h*.

Occasionally, responding continued through all four components of the mixed cycle and ended with punishment (*i* and *j*).

The cumulative records of Fig. 2 and 4 indicate that more shocks were delivered at the end of the tandem and mixed cycles than at the end of the chained and multiple cycles. Table 4 shows the total number of shocks delivered to each pigeon in the last five sessions of each condition. Except for the chained-and-tandem sessions at high shock levels when sessions were sometimes terminated before 30 cycles, the maximum number of shocks in any condition for five sessions was 75, since there were 15 cycles of each condition per session. The table indicates that as shock intensity was increased, the number of shocks delivered decreased. In every case but one (Pigeon 42 on the multiple-and-mixed procedure at 4 mA), the number of shocks presented in the one-stimulus cycles (tandem and mixed schedules)

Table 3

Rates (responses per minute) in the four components of the multiple and mixed punishment schedules for each pigeon at each shock intensity. Rates shown are medians and ranges of the last five sessions in each condition. For each pigeon, the baseline and the intensity marked with an asterisk are those plotted in Fig. 3. Shock was not delivered to Pigeon 220 at 6 mA because one electrode was disconnected.

Pigeon	Intensity (mA)	Multiple				Intensity (mA)	Mixed			
		1	2	3	4		1	2	3	4
42	0	105	107	104	136	0	113	104	99	97
		94-115	96-126	92-113	108-149		95-121	95-118	75-117	74-116
	2	139	128	124	117	2	106	96	111	108
		131-150	97-129	116-133	96-129		87-128	84-117	76-113	85-119
	4*	116	112	107	58	4*	86	74	63	48
		71-136	86-127	104-135	27-92		18-98	12-97	4-93	2-80
	6	112	116	105	41	6	82	87	69	47
		82-152	76-121	67-131	25-53		61-110	59-108	54-93	33-58
	8	113	128	106	26	8	59	49	25	8
		76-144	91-135	68-125	4-45		35-103	28-95	12-84	4-57
220	0	51	43	43	47	0	32	33	31	28
		37-70	40-61	38-55	43-78		30-48	28-51	26-44	20-44
	2	74	65	64	61	2	54	56	51	48
		68-81	49-76	51-81	55-67		46-67	46-61	41-59	40-56
	4*	30	43	21	17	4*	13	6	6	7
		18-88	23-94	14-88	7-83		8-68	5-72	4-69	3-67
	6	—	—	—	—	6	—	—	—	—
		—	—	—	—		—	—	—	—
	8	2	0	1	0	8	0	0	0	0
		0-20	0-30	0-15	0-3		0-2	0-1	0-1	0-1
221	0	87	102	107	99	0	105	91	86	78
		70-90	100-109	104-116	69-111		92-106	81-105	74-95	75-94
	2	83	106	115	100	2	99	83	89	87
		72-86	103-116	109-133	86-107		79-105	67-111	49-106	33-101
	4	81	118	117	98	4	102	96	79	74
		70-87	107-121	107-120	56-104		89-113	78-103	69-101	64-97
	6*	72	107	92	20	6*	62	41	19	3
		38-86	59-123	45-107	9-28		15-67	6-54	0-36	0-6
	8	70	101	82	18	8	65	26	11	5
		35-98	43-118	32-95	2-19		10-67	1-46	1-26	0-6
223	0	84	88	99	99	0	77	71	73	74
		64-95	62-92	71-120	76-109		60-92	68-107	60-103	59-100
	2*	89	78	83	35	2*	60	57	43	25
		77-101	60-84	75-102	27-37		34-65	21-65	15-50	15-28
	4	94	104	91	14	4	56	39	20	5
		62-110	64-118	58-95	9-25		18-67	7-68	2-35	1-7
	6	75	94	84	11	6	51	50	31	8
		50-89	77-118	71-100	10-12		33-69	24-58	13-43	3-10
	8	69	68	51	2	8	37	13	0	0
		40-77	24-77	20-69	0-15		7-44	0-22	0-11	0-0

was equal to or greater than the number presented in the four-stimulus cycles (chained and multiple schedules).

At high intensities of shock, response rates were suppressed in the fourth component (and sometimes other components) of all conditions. Since reinforcement was available on an

interval schedule, fewer than the maximum scheduled reinforcements occurred when rates were low. Table 4 shows the total number of reinforcements for each pigeon in each component in the last five sessions of each condition. Four one-way analyses of variance, one each on tandem, chained, mixed, and multiple

Table 4

Total number of reinforcements and shocks during the last five sessions of each condition at each shock intensity.*

Pigeon	Intensity (mA)	Chain					Tandem					Multiple					Mixed				
		1	2	3	4		1	2	3	4		1	2	3	4		1	2	3	4	
42	0	23	31	40	45	—	50	32	38	40	—	28	40	50	54	—	33	25	29	32	—
	2	43	37	33	31	(75)	19	31	53	38	(75)	28	36	48	39	(75)	25	27	51	46	(75)
	4	31	23	26	24	(51)	42	61	49	32	(73)	31	40	32	34	(44)	25	25	16	32	(40)
	6	8	14	12	10	(4)	14	24	18	19	(24)	50	44	37	34	(60)	34	23	35	46	(65)
	8	7	12	15	9	(4)	9	19	20	14	(10)	35	39	39	26	(40)	25	25	16	26	(48)
220	0	40	40	44	29	—	22	28	45	49	—	26	24	31	35	—	40	44	47	37	—
	2	55	42	34	25	(75)	23	36	37	50	(75)	43	37	41	30	(75)	15	31	43	55	(75)
	4	25	28	45	50	(75)	43	40	33	33	(75)	27	20	30	33	(50)	14	16	22	34	(50)
	6	35	42	35	39	(60)	14	20	25	36	(60)	—	—	—	—	—	—	—	—	—	—
	8	20	27	28	29	(35)	23	30	32	37	(56)	3	3	9	0	(3)	1	1	1	1	(3)
221	0	40	35	27	29	—	41	55	39	31	—	29	38	37	37	—	39	39	43	42	—
	2	38	29	28	34	(75)	41	32	33	48	(75)	47	30	35	27	(71)	38	30	37	45	(73)
	4	43	39	46	47	(75)	42	28	23	30	(75)	42	45	39	40	(68)	33	40	29	29	(75)
	6	38	31	37	36	(26)	27	40	35	39	(58)	27	37	39	20	(10)	19	6	15	13	(11)
	8	29	27	38	28	(17)	32	35	35	44	(31)	20	25	28	16	(1)	8	15	13	8	(3)
223	0	43	27	25	37	—	49	44	37	38	—	42	47	49	30	—	25	25	33	34	—
	2	32	34	44	31	(75)	36	35	47	38	(75)	32	28	37	42	(68)	32	22	34	41	(74)
	4	31	29	44	16	(13)	16	38	42	39	(39)	32	36	29	17	(9)	19	25	20	19	(23)
	6	12	24	16	10	(2)	9	28	19	20	(15)	30	27	38	13	(3)	23	20	28	11	(13)
	8	17	11	19	11	(6)	20	21	28	27	(15)	19	27	38	12	(1)	12	14	4	5	(3)

*The first four numbers under each condition are reinforcements in each component; the numbers in parentheses are total number of shocks. There are no data given for Pigeon 220 at 6 mA in the multiple and mixed conditions because an electrode was disconnected.

conditions, across pigeons, showed no significant difference between components (Tandem, $F_{3,76} = 1.4324$, Chain, $F_{3,76} = 0.3357$, Mixed, $F_{3,75} = 1.0809$, Multiple, $F_{3,75} = 1.6667$, $p > 0.05$ in all cases). Thus, although there were fewer reinforcements at higher intensities of shock, there were no significantly different frequencies of reinforcement among the several components.

DISCUSSION

The present findings show that responding was reduced most in the presence of the stimulus that terminated with a response-produced electric shock. In the chained and multiple schedules this was the stimulus in the fourth component; in the tandem and mixed schedules this was the single stimulus correlated with those schedules.

When shock followed a response in the presence of the last of a series of four stimuli, the rate during that stimulus was suppressed, while the rate during the first three stimuli was less affected. This occurred both when the

delivery of the successive stimuli was dependent on a response (chained schedule), and when it was automatic (multiple schedule). For three of the pigeons (42, 221, and 223) on the chained schedule, and for two (221 and 223) on the multiple schedule, there was also suppression of responding relative to the baseline in the third component. This finding that punishment effects can be brought under stimulus control is similar to that of Azrin (1956), who studied two-component multiple schedules in which punishment on a fixed-interval occurred in only one of the components. He found that rate in the component with no punishment was not affected, except for an occasional but not reliable increase.

In the present experiment, rates in the components during which shocks were not delivered did not consistently increase, as might be expected from earlier studies (*e.g.*, Brethower and Reynolds, 1962; Terrace, 1968). Brethower and Reynolds (1962), for example, delivered shock after every response in one component of a two-component multiple schedule, and found an increase in rate in the other (no-

Fig. 4. Sample cumulative records from the multiple-and-mixed punishment sessions. The mixed cycles are underlined. The response pen reset at the end of each cycle. The flat section after reset indicates the timeout between cycles. There is a diagonal pip on the response record at the end of the timeout and at the end of each of the first three components; there is also a pip after 30 sec in the fourth component. If the cycle ended with a shock there is no pip before reset; if the limited hold ended the cycle there is a pip before reset. Food presentations are not indicated in the records. The top record is from a baseline session. The middle record is from a session with 8 mA for Pigeon 42; the lower record is from a session with 6 mA for Pigeon 223.

shock) component. One important difference between these studies in which the punishment contrast effect is noted and the present study (as well as that of Azrin, 1956) is the schedule of shock delivery. Whereas Brethower and Reynolds (1962) and Terrace (1968) presented shock after every response in the punishment component (FR 1), in the present study shock occurred on a fixed-interval schedule. In addition to this difference, the present experiment involved more complex multiple schedules. Punishment occurred in only one of four components of the multiple schedule and was followed by a timeout, the intervening mixed schedule, and another timeout before the next multiple cycle. Thus, both the schedule of shock delivery and the complex inter-

actions of the multiple-mixed schedules may be responsible for the present failure to find an increase in rate during the stimuli not correlated with shock.

The similarity between performance on the chained and multiple schedules of punishment indicates that the stimuli in the early components of the chained schedule did not acquire strong conditioned punishing properties. The stimuli of the chained and multiple schedules controlled different rates of responding, and whether the successive stimuli were response-produced or response-independent was relatively unimportant to this control. Stimuli in the first three components controlled high rates; the stimulus in the fourth component controlled a low rate. The chief determinant

of this stimulus control was not that the stimuli in the second, third, and fourth components were paired with shock or a conditioned aversive stimulus, but rather that those in the first, second, and third components were stimuli in whose presence shock never occurred and food presentation did. The stimuli in the first three components of the chained and multiple schedules were, in effect, safe stimuli.

When shock followed a response at the end of four components in the presence of a single stimulus, response rate was suppressed in all four components, with rate decreasing over successive components. This occurred both when component change was response-dependent (tandem schedule) and when it was not (mixed schedule). These results are similar to those of Azrin (1956) who examined fixed-interval schedules of shock presentation; in these schedules, response rate decreased as the end of the interval approached. In fact, the mixed schedule of the present experiment is identical to an FI 2-min schedule of punishment with a 30-sec limited hold. The negatively accelerated rate over the interval is complementary to the "scallop" of FI schedules of food reinforcement (Ferster and Skinner, 1957), in which rate is positively accelerated over the interval. The similarity of performances on the tandem and mixed schedules indicates that the component-change dependency of the tandem schedule did not have much effect on the performance.

The multiple and mixed schedules of shock presentation are similar to schedules examined by Hendry, Yarczower, and Switalski (1969). These investigators delivered shocks to rats every 6 min while responding was maintained on a VI schedule of food presentation. In one condition, similar to the present multiple schedule, three different stimuli, or clock cues, were presented for 2 min each between the response-independent shocks. In another condition, similar to the present mixed schedule, a single stimulus was present between shocks. As in the present study, overall rates were higher when cues were present than when they were not, and rates were lowest in the component correlated with shock-delivery. The chief difference in the findings is that Hendry *et al.* (1969) found that rates decreased from the first through last components both with cues and without, while in the present

experiment this occurred only in the one-stimulus (mixed) schedule. In the multiple schedule, rates remained high and relatively constant during the first three components and decreased only in the fourth. This difference may be due in part to the fact that shock delivery was response-independent in the Hendry *et al.* experiment and response-dependent in the present study. A more likely reason for this difference may be the above-noted absence of behavioral contrast effects in the present study. Hendry *et al.* suggested that the relatively high rate in the first component after shock in their study is an example of the punishment contrast effect (Azrin and Holz, 1966). With no reliable behavioral contrast in the present multiple schedule, there was no decrease in rate from the first through the fourth component.

The results on the chained and tandem schedules may be compared to evaluate the effects of conditioned punishment in the former. Rates were low in the fourth component of both schedules. In the first three components, however, rates on the tandem schedule were consistently lower than those on the chained schedule, *i.e.*, there was far greater suppression in the early components of the tandem schedule. This result is opposite to what might be expected if the consecutive stimuli of the chained schedule had become conditioned punishers. A stimulus in whose presence responding was punished might have become a conditioned punisher for responding in the previous component. However, this was not the case in the first two components of the chained schedule, since responding in these components was either little affected (Pigeons 42, 221, and 223) or greatly increased (Pigeon 220) when compared with the baseline, and was in all cases higher than responding on the tandem schedule. Conditioned punishment may therefore be discounted in the first two components of the chained schedule.

Performances on the chained and tandem schedules of punishment are also complementary to those found on extended chained and tandem schedules of food reinforcement (Golub, 1958; Kelleher and Fry, 1962). In these latter schedules, there was long pausing in the early components of the chained, and much less pausing in the early components of the tandem schedules. Similarly, there was little or no suppression in the early components of

the chained schedules of punishment and considerable suppression in the early components of the tandem. However, Kelleher and Fry (1962) also concluded that the stimulus in the final component of a three-component reinforcement chain was a conditioned reinforcer for responding in the penultimate component. The suppression in the third component of the chained schedule of punishment for three of the pigeons may, by analogy, be attributed to the conditioned punishing effects of the stimulus of the terminal component.

One significant limitation to this analogy between the chained schedules of punishment of the present study and chained schedules of reinforcement arises from the limited-hold contingency of the former. In the punishment study, shock could be avoided, whereas in the food reinforcement studies, food was always presented. In the reinforcement case, the terminal stimulus indicates the approach of food delivery, while in the punishment case, the terminal stimulus indicates either the approach of shock delivery or the opportunity to avoid the shock. The limited hold may have been responsible for the almost complete suppression in the fourth component of the chained schedule. As Azrin (1956) showed in his study of discriminated punishment, suppression was greater in those procedures in which shock could be avoided than in those in which it could not.

REFERENCES

- Azrin, N. H. Effects of two intermittent schedules of immediate and nonimmediate punishment. *Journal of Psychology*, 1956, 42, 3-21.
- Azrin, N. H. A technique for delivering shock to pigeons. *Journal of the Experimental Analysis of Behavior*, 1959, 2, 161-162.
- Azrin, N. H. and Holz, W. C. Punishment. In W. K. Honig (Ed.), *Operant behavior: areas of research and application*. New York: Appleton-Century-Crofts, 1966. Pp. 380-447.
- Brethower, D. M. and Reynolds, G. S. A facilitative effect of punishment on unpunished behavior. *Journal of the Experimental Analysis of Behavior*, 1962, 5, 191-199.
- Catania, A. C. and Reynolds, G. S. A quantitative analysis of the responding maintained by interval schedules of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1968, 11, 327-383.
- Ferster, C. B. and Skinner, B. F. *Schedules of reinforcement*. New York: Appleton-Century-Crofts, 1957.
- Gollub, L. R. *The chaining of fixed-interval schedules*. Unpublished Ph.D. dissertation, Harvard University, 1958.
- Hendry, D. P., Yarczower, M., and Switalski, R. C. Periodic shock with added clock. *Journal of the Experimental Analysis of Behavior*, 1969, 12, 159-166.
- Kelleher, R. T. and Fry, W. T. Stimulus functions in chained fixed-interval schedules. *Journal of the Experimental Analysis of Behavior*, 1962, 5, 167-173.
- Miller, N. E. Learning resistance to pain and fear: effects of overlearning, exposure and rewarded exposure in context. *Journal of Experimental Psychology*, 1960, 60, 137-145.
- Ramsay, D. A., Knapp, J. Z., and Zeiss, J. C. Transients in "constant-current" generators. *Behavior Research Methods and Instrumentation*, 1970, 2, 122-123.
- Segal, E. F. Exteroceptive control of fixed-interval responding. *Journal of the Experimental Analysis of Behavior*, 1962, 5, 49-57.
- Terrace, H. S. Discrimination learning, the peak shift, and behavioral contrast. *Journal of the Experimental Analysis of Behavior*, 1968, 11, 727-741.

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