JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR 1981, 35, 55-67 NUMBER 1 (JANUARY)

AN INTERRESPONSE TIME ANALYSIS OF VARIABLE-RATIO PUNISHMENT

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An interresponse time analysis was used to study the effects of variable-ratio punishment schedules on the temporal pattern of reinforced responding. Twelve pigeons responded on a baseline variable-interval schedule of food reinforcement. A variable-ratio ten schedule of electric shock punishment was then introduced. The shock intensity was systematically increased to the highest intensity at which responding could be maintained. At this intensity, the mean variable-ratio value was increased and then decreased. Variable-ratio punishment resulted in an increased relative frequency of very short unreinforced interresponse times (response bursting). Increased response bursting accounted for instances of response rate facilitation. In addition, shock was followed by interresponse times of decreasing mean length over the first several responses after shock.

Key words: variable-ratio punishment, variable-interval reinforcement, interresponse time, response bursting, facilitation, key peck, pigeons

Intermittent schedules of punishment occasionally result in rates of reinforced responding that are greater than the previously unpunished baseline rate (Appel, 1968; Filby & Appel, 1966; Sandler, 1964; Snapper, Schoenfeld & Locke, 1966). When electric shock is used as the punishing stimulus, response rate facilitation generally occurs at relatively low shock intensities. This effect is not by definition an instance of punishment (cf., Azrin & Holz, 1966) nor can electric shock be considered a punisher since the overall session rate is not decreased. Yet, at a given shock intensity the occurrence of facilitation is often inconsistent across subjects and over sessions of exposure for the same subject. Thus, a particular shock intensity may or may not have punishing effects.

It is possible that intermittent, response-contingent shock may have both punishing and facilitative effects within a session. Such effects are not apparent in cumulative records or overall response rate data. In other research areas, interresponse time (IRT) measures have proven useful for such fine-grained analyses. Previous studies collecting IRT distributions in the study of punishment (Bruner, 1967; Holz & Azrin, 1963; Holz, Azrin, & Ulrich, 1963; Malott & Cumming, 1964b) have not addressed the question of within-session punishing and facilitative effects of shock. The present study used an IRT analysis in the hope of uncovering systematic changes in the temporal distribution of responding which could be used to assess both response rate increases and decreases during intermittent punishment.

METHOD

Subjects

Twelve male White Carneaux pigeons were maintained at 80% of their free-feeding body weights throughout the experiment. Water was available only in the home cage. Before the present experiment, all subjects had received variable-interval 1-minute (VI 1-min) reinforcement training for a total of about 60 sessions. During that time, all subjects were also exposed to one of several schedules of punishment (either fixed-ratio 1 or variable-ratio 3, 6, or 10), for about 30 of those sessions.

This paper is based on a dissertation submitted by Stephen D. Lande to the Faculty of the Graduate School of Arts and Sciences of Boston University in partial fulfillment of the requirements for the PhD degree. Sincere appreciation is extended to Henry Marcucella and Donald Overton for their comments and suggestions, Charles Abramson for his help in data collection, and William Marshall for his assistance in computer programming. Reprints may be obtained from Stephen D. Lande, Department of Psychiatry, Temple University School of Medicine, c/o Eastern Pennsylvania Psychiatric Institute, Henry Avenue, Philadelphia, Pennsylvania 19129.

Apparatus

Two experimental pigeon chambers (Gerbrands model #7313 and #7311) were separately housed in sound and light attenuating enclosures (Grason Stadler model #1101 and Gerbrands model #7210, respectively). Each chamber contained a translucent response key which could be transilluminated with a green light. The response key was located directly over the food magazine. Key pecks of at least .5 N were recorded and operated a feedback relay mounted behind the front panel.

The reinforcer consisted of a 3.0-sec access to mixed grain from the food magazine. During reinforcer presentations the key light and 1.0-W houselight were darkened, and the food magazine was illuminated by two 1.0-W lamps. The keylight and houselight remained on throughout the session, except during reinforcer presentations. Masking noise was provided by a white noise generator and exhaust fan.

The punishing stimulus was electric shock, delivered through stainless steel electrodes implanted around each of the birds' pubis bones. The two electrodes for each bird were wired to a plug, attached to a harness, and fitted over the wings and across the birds back (Azrin, 1959). A matching socket was attached to a short coiled cord which led to a mercury filled commutator. The commutator was mounted on the top of each pigeon chamber and allowed for free movement around the chamber. Electric shock was presented for 100 msec, at 350V for up to 4.0 mA, and at 700 V for 5.0 mA and greater. An independent shock generator was separately wired to each pigeon chamber (Grason-Stadler model #700 and #E1064, modified to duplicate the characteristics of the model #700). The total resistance through each bird was measured at the shock source before each session. Measurements were made with a Simpson model #160 Volt-Ohmmeter (20,000 ohms/volt) and equaled 5 ± 2 k-ohms. The shock electrodes were cleaned when resistance became greater than 7k-ohms.

Solid state programming and recording equipment were located in an adjacent room. Events from both pigeon chambers were recorded sequentially by a Kennedy model #1400/360 9-track incremental magnetic tape recorder. Later in the experiment a Kennedy model #1600/360 was used. Aside from data collected on counters and timers, all data analysis was done on an IBM System/370 Model 158 computer.

Procedure

Key pecks were reinforced on a variable-interval (VI) schedule of reinforcement, with a mean interreinforcement time of one minute (VI 1-min). The VI 1-min interreinforcement intervals were, in seconds: 216, 3, 79, 30, 126, 60, 13, 156, 53, 17, 68, 6, 21, 35, 40, 106, 10, 45, 91, and 25. The intervals were derived from Catania and Reynolds (1968), and have been shown to maintain stable responding. Variable-interval 1-minute baseline training was continued for 30 1-hr sessions.

Subjects were then exposed to a variable-ratio schedule of punishment, with a mean ratio of 10 (VR10). The sequence of ratios was generated by a probability generator (Massey-Dickenson model #ROC/P59) which provided a Poisson-distributed output. A sequence of increasing shock intensities (4.0 mA, 5.0 mA, 6.0 mA, 8.0 mA, 10.0 mA, 13.0 mA, 16.0 mA), was presented to each subject, for 10 sessions at each intensity. (Bird 190 was started at 2.5 mA after he failed to respond at 4.0 mA). If responding ceased or became very erratic at a particular intensity (frequent long pauses lasting several minutes for two successive sessions), this phase of the experiment was terminated for a given subject. Data from these two shock sessions when responding was very erratic were deleted from analysis. In addition, initial exposure to each shock intensity was preceded by a period of several shock presentations of a slightly lowered intensity value. This procedure was used in order to prevent the complete disruption of responding which has often been observed (e.g., Azrin, 1960) upon initial exposure to sudden increases in the intensity of electric shock.

The second phase of the experiment involved systematic variation of the mean punishment ratio. Subjects were exposed to the following series of VR punishment schedules for 10 sessions each: VR100, VR400, VR800, VR400, VR100, and VR10. The shock intensity was set at the final intensity used in Phase 1 of the experiment (i.e., before responding ceased) and held constant throughout the remainder of the experiment. The sequence of ratios for each VR schedule (except VR10, previously mentioned), was generated by a Grason-Stadler model #1079 tape counter. The tape intervals for VR400 and VR800 were multiplicative values of those used for VR100, namely: 31, 166, 53, 70, 146, 100, 71, 123, and 140 responses.

RESULTS

Table 1 shows the mean rate of responding for each subject during the last 5 sessions of unpunished baseline (0) and the last 5 sessions of VR10 punishment at each specified shock intensity. These rate data were calculated from the total number of responses and total session time (excluding the total duration of reinforcer presentations), collected on electromechanical counters and timers.

For 5 of the 12 subjects, the overall rate of responding was inversely related to shock intensity (Birds 69, 253, 269, 278, and 283). The remaining 7 subjects showed an increase over the baseline rate of responding, either when VR10 punishment was first introduced at the lowest intensity used (Birds 187, 190, 194, and 268), or at higher shock intensities (Birds 16, 85, and 94). The shock intensity at which such increased response rates were obtained varied across subjects. At some point for all subjects, increasing the intensity of electric shock produced a response rate which was lower than that observed for the previously unpunished baseline.

The effects on response rate of a particular intensity of VR10 punishment clearly differed across subjects. For example, the introduction of 4.0-mA shock produced a marked decrease in the response rate of Bird 278. In contrast, the response rates of Birds 187, 194, and 268 increased at the same intensity. In addition, the maximum intensity at which responding could be maintained also varied widely over subjects. For example, Bird 278 did not continue to respond at shock intensities greater than 4.0 mA. In contrast, Bird 94 responded steadily at shock intensities up to 16.0 mA.

IRTs were sorted into 1 of 11 IRT class-interval bins. The first 10 of these have a bin width of .20 sec. Bin 11 contains all IRTs greater than 2.0 sec. The relative frequency of IRTs in each bin was averaged over the last 5 sessions of a given condition. Figures 1 through 3 show the mean relative frequency for overall IRTs (solid lines) and reinforced IRTs (dashed lines) for each IRT class interval bin, for all subjects and conditions where such data are available. The intensity of VR10 punishment shock is specified. Failure of the magnetic tape unit prevented collection of IRT data for several conditions for which response rate data

Table 1

The Mean Response Rate By Subject for Each Shock Intensity Condition

Shock Intensity (mA)	*Subject*											
	16	*69*	*85*	*94*	*187*	*190*	*194*	*253*	*268*	*269*	*278*	*283*
	Mean Response Rate (response/minute)											
.0	100.1 (6.3)	86.8 (4.9)	64.4 (2.3)	38.6 (3.1)	120.5 (3.1)	22.7 (2.3)	68.7 (4.5)	110.6 (3.8)	65.1 (4.8)	108.8 (4.6)	77.2 (4.2)	63.7 (1.4)
2.5						34.8 (2.1)						
4.0	81.8 (9.1)	22.8 (8.0)	55.2 (11.3)	30.7 (6.1)	128.2 (5.6)	19.0 (2.4)	72.1 (6.7)	75.9 (17.1)	79.9 (5.4)	34.3 (6.1)	4.5 (1.5)	58.3 (4.0)
5.0	138.1 (4.4)	8.0 (3.0)	44.2 (6.7)	35.5 (2.5)	93.5 (2.6)	10.3 (3.1)	26.4 (2.6)	56.3 (13.9)	72.2 (4.1)	13.8 (3.0)		30.1 (2.2)
6.0	111.8 (7.6)		67.4 (3.4)	46.9 (3.2)	68.6 (4.6)		16.8 (2.7)	39.4 (8.1)	74.8 (5.8)	11.6 (3.6)		6.1 (0.9)
8.0	20.5 (5.5)		12.3 (2.1)	41.2 (6.0)	16.8 (5.2)		16.7 (1.3)	14.0 (5.8)	37.7 (5.3)			
10.0	9.6 (3.1)			30.3 (1.3)	8.1 (4.1)		8.2 (2.9)		15.3 (3.0)			
13.0				32.0 (1.3)								
16.0				16.0 (2.4)								

Standard Deviations (in parentheses)

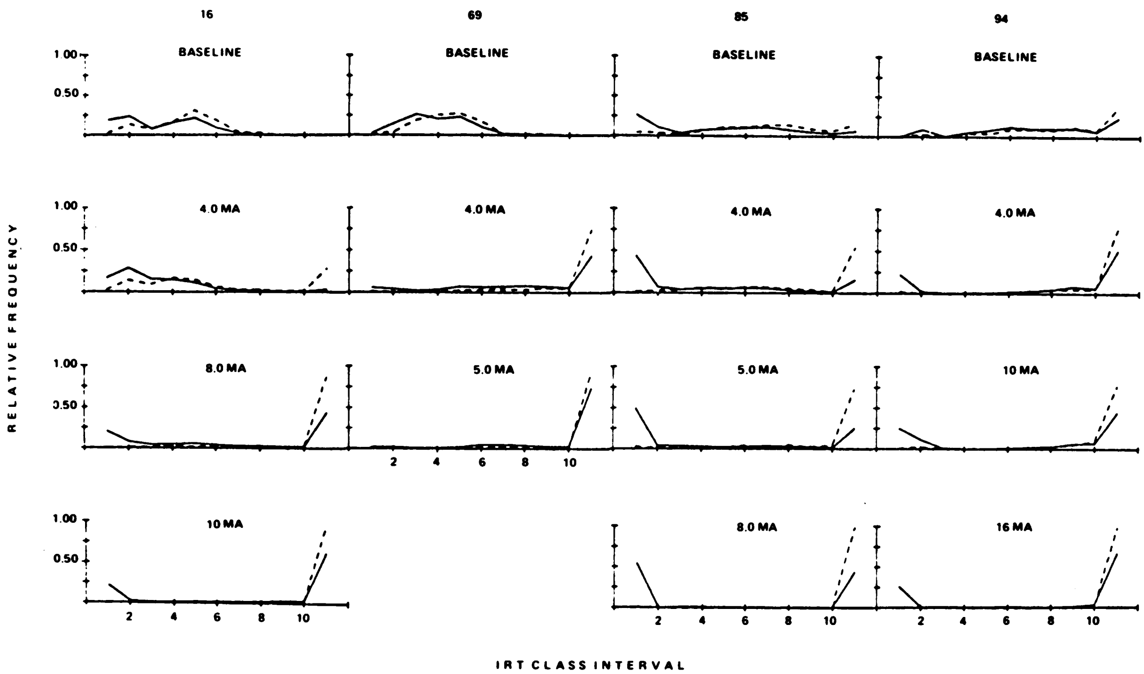

Fig. 1. The mean relative frequency for overall IRTs (solid lines) and reinforced IRTs (dashed lines) averaged over the last five sessions of unpunished baseline and VR10 punishment at the specified shock intensity for Subjects 16, 69, 85, and 94. The IRT class interval binwidth is equal to .20 sec with all IRTs greater than 2.0 sec represented in the 11th IRT class interval.

were presented in Table 1. For this reason, no IRT data were collected for Bird 187.

Figures 1 through 3 show that during VR10 punishment, the relative frequency of short overall IRTs (less than or equal to .20 sec, Bin 1) typically increased over that observed during the previously unpunished baseline. This occurred for 10 of 11 subjects (exception is Bird 278) regardless of whether VR10 punishment at the specified intensity decreased the rate of responding. The trend analysis showed that the relative frequency of short overall IRTs (Bin 1) was directly related to shock intensity ($F = 17.13$, $df = 1/8$, two-tail, $P < .01$). In addition, the relative frequency of long overall IRTs (greater than 2.0 sec, Bin 11) also tended to increase with shock intensity, while .2- to 2.0-sec IRTs (Bins 2 to 10) decreased in relative frequency. Figures 1 through 3 also show that although long IRTs (Bin 11) continued to be reinforced throughout VR10 punishment, short IRTs (Bin 1) were infrequently reinforced.

In order to determine whether the overall IRT distribution changes during VR10 punishment could be separated into immediate and subsequent effects of shock, IRTs which immediately followed shock were separated from all other IRTs. For this experiment postshock IRTs were defined as those IRTs which began with a response immediately followed by shock. Postresponse IRTs were defined as those IRTs which did not begin with a shocked response. Thus, postresponse IRTs were all those IRTs which occurred in a session (overall IRTs), excluding the postshock IRTs. IRT relative frequency distributions were calculated for postshock and postresponse IRTs, just as they were for overall and reinforced IRTs, described previously.

Table 2 shows the mean relative frequency of short (Bin 1) and long (Bin 11) postshock and postresponse IRTs averaged over the last 5 sessions of a given condition. When the shock intensity is equal to 0 (unpunished baseline), the mean relative frequencies for postresponse IRTs equalled those for overall IRTs. These data show that a much greater proportion of postresponse IRTs were short (Bin 1) than the proportion of postshock IRTs which were

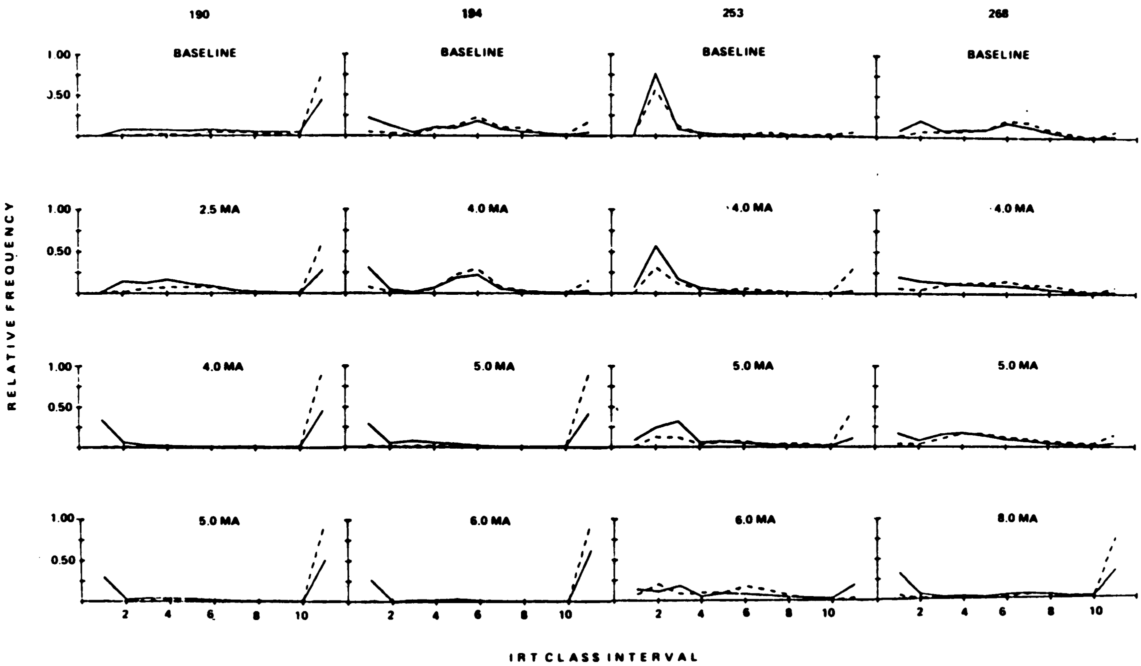

Fig. 2. Same as Figure 1 for Subjects 190, 194, 253, and 268.

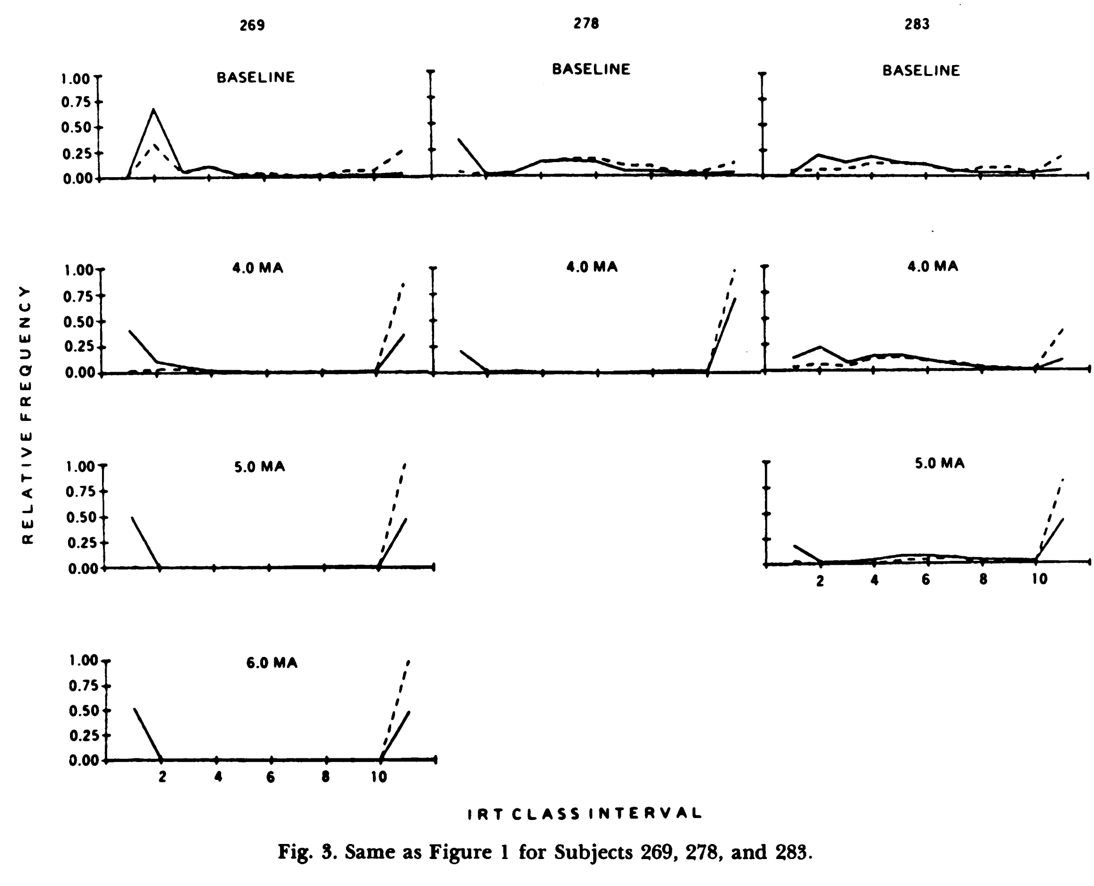

Fig. 3. Same as Figure 1 for Subjects 269, 278, and 283.

Table 2

The mean relative frequency for postshock and postresponse IRTs in IRT class interval 1 (0.0 to .2 sec) and 11 (greater than 2.0 sec) by subject for each shock intensity condition.

Shock Intensity (mA)	Subject 16		69		85		94		190		194		253		268		269		278		283	
	IRT Class Interval Bin 1	11	1	11	1	11	1	11	1	11	1	11	1	11	1	11	1	11	1	11	1	11
	Postshock IRTs (mean relative frequency)																					
2.5									.005	.407												
4.0	.255	.038	.000	.952	.280	.364	.004	.740	.141	.728	.045	.094	.048	.109	.114	.051	.356	.560	.030	.962	.038	.190
5.0			.000	.975	.279	.531			.057	.609	.055	.891	.014	.239	.096	.081	.422	.576			.072	.670
6.0											.031	.959	.011	.378	.120	.131	.469	.533			.069	.931
8.0	.137	.518			.394	.606	.038	.391							.147	.615						
10.0	.075	.815					.008	.670														
13.0							.005	.609														
16.0							.005	.971														
	Postresponse IRTs (mean relative frequency)																					
.0	.190	.003	.030	.002	.261	.063	.010	.240	.009	.436	.223	.045	.025	.008	.076	.032	.012	.034	.349	.033	.023	.062
2.5									.012	.258												
4.0	.278	.040	.064	.375	.459	.127	.252	.478	.368	.427	.347	.030	.072	.027	.209	.025	.420	.328	.227	.667	.132	.084
5.0			.026	.711	.520	.216			.332	.498	.332	.368	.087	.091	.178	.040	.509	.462			.196	.398
6.0											.295	.584	.153	.173	.297	.057	.522	.472			.159	.741
8.0	.206	.428			.561	.421	.313	.247							.341	.311						
10.0	.227	.609					.277	.416														
13.0							.291	.429														
16.0							.290	.630														

short. That is, short IRTs tended to occur most frequently during periods not initiated by a shocked response.

The means for IRTs after the postshock IRT were also collected. Thus, the present analysis attempted to determine the response-rate trend after shock. In addition, changes in the response-rate trend after shock were examined as a function of increasing shock intensity.

The IRT sequence after shock included all IRTs following a shocked response, providing that neither the presentation of another shock, nor the delivery of a reinforcer intervened. The means for the first 10 IRTs after shock were calculated for every session. For graphic clarity and consistency, the IRT data collected for each subject were separated into three relative shock intensity categories: low, moderate, and high intensity shock; according to absolute shock intensity used (see Table 2). For Birds 94 and 268, data were available for more than three shock intensity conditions. Thus, data from every other shock intensity condition are shown for Bird 94; and from all but 6.0-mA shock for Bird 268.

Figure 4 provides the means for each of the first 10 IRTs after shock averaged over the last five sessions of a given condition. The first IRT after shock (postshock IRT) is generally longer than subsequent IRTs. A downward trend in mean IRT over the first several IRTs after shock is apparent especially at higher shock intensities. No consistent change in the shape of the curves can be detected as a function of shock intensity. An examination of the means for IRTs more than 10 responses after shock (not shown) revealed no consistent change in rate before the next shock.

Table 3 shows the mean rate of responding during the last five sessions of exposure to the specified VR punishment schedule. All rate data were calculated from the total number of responses and total session time (excluding the total duration of reinforcer presentations) collected on electromechanical counters and timers. Overall, the rate of responding was directly related to the VR punishment schedule value.

Figure 5 shows the mean relative frequency of overall IRTs (solid lines) and reinforced IRTs (dashed lines) in each of 11 IRT class interval bins. The relative frequency of IRTs in each bin was averaged over the last five sessions of exposure to a given VR punishment schedule for all conditions where such data were collected. The bin width is equal to .20

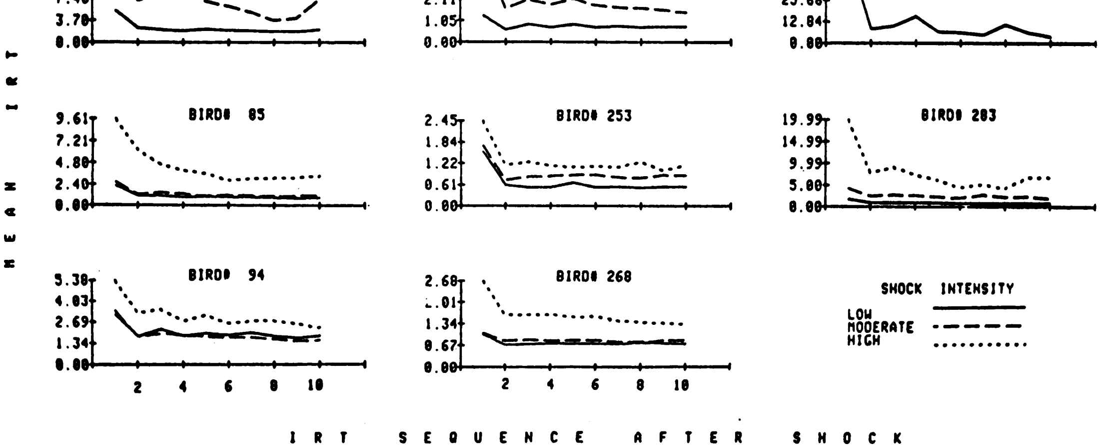

Fig. 4. The means (in seconds) for the first 10 IRTs after shock, by subject, averaged over the last five sessions of each shock intensity condition. The ordinate differs for each subject.

Table 3

The Mean Response Rate By Subject for each VR Punishment Schedule

Punishment Schedule VR	*Subject*											
	16	*69*	*85*	*94*	*187*	*190*	*194*	*253*	*268*	*269*	*278*	*283*
	Mean Response Rate (responses/minute)											
10	9.6	8.0	12.3	16.0	8.1	7.6	8.2	14.0	15.3	8.7	4.5	6.1
	(3.1)	(3.0)	(2.1)	(2.4)	(4.1)	(3.2)	(2.9)	(5.8)	(3.0)	(4.2)	(1.5)	(.9)
100	39.5	25.8	19.3	30.2	25.0	31.4	21.9	26.1	17.0	22.2	16.6	12.0
	(8.2)	(9.4)	(1.9)	(3.8)	(3.4)	(3.5)	(5.7)	(6.0)	(5.6)	(6.9)	(4.8)	(3.7)
400	81.5	44.4	33.2	32.9	66.6	72.1	40.2	47.4	46.7	41.6	17.1	27.1
	(7.1)	(10.4)	(3.2)	(2.1)	(5.0)	(13.2)	(4.2)	(4.7)	(8.1)	(11.1)	(7.4)	(5.7)
800	82.4	65.8	44.2	37.1	95.3	77.1	54.8	56.3	51.8	103.5	21.4	36.7
	(16.6)	(9.3)	(9.9)	(2.6)	(5.0)	(5.2)	(5.3)	(10.4)	(10.2)	(16.2)	(4.7)	(2.9)
400	52.2	62.3	27.0	23.0	79.3	63.3	39.5	26.5	49.6	75.1	19.4	18.2
	(3.4)	(5.6)	(4.6)	(1.5)	(5.3)	(1.3)	(3.8)	(5.7)	(2.3)	(7.9)	(5.3)	(4.0)
100	14.9	34.2	14.3	14.9	25.6	36.0	26.6	16.6	30.7	34.1	11.0	5.9
	(2.4)	(3.5)	(3.9)	(6.7)	(6.6)	(2.3)	(3.0)	(2.5)	(4.8)	(4.3)	(3.3)	(.8)
10	4.7	10.0	5.1	8.5	9.2	6.0	6.9	7.7	8.9	9.1	3.5	2.8
	(1.0)	(3.1)	(2.2)	(1.6)	(1.3)	(2.6)	(1.1)	(4.0)	(1.6)	(2.8)	(1.2)	(.7)
Shock Intensity (mA)	*10.0*	*5.0*	*8.0*	*16.0*	*10.0*	*6.0*	*10.0*	*8.0*	*10.0*	*6.0*	*4.0*	*6.0*

Standard Deviations (in parentheses)

sec, with all IRTs greater than 2.0 sec represented in Bin 11. The shock intensity (in mA) used for each subject is listed in Table 3. Failure of the magnetic tape unit prevented collection of IRT data for several subjects for which response rate data were presented in Table 3.

The relative frequency of short (Bin 1) IRTs did not systematically vary with VR punishment schedule value. Although a high relative frequency of short IRTs was often maintained, short IRTs were infrequently reinforced. The relative frequency of long (Bin 11) IRTs was inversely related to the VR punishment schedule value. These were frequently reinforced.

IRTs which immediately followed shock (postshock IRTs) were again separated from IRTs which did not begin with a shocked response (postresponse IRTs). Table 4 shows the mean relative frequency of short (Bin 1) and long (Bin 11) postshock and postresponse IRTs, each averaged over the last five sessions of a given condition. These data show that a far greater proportion of postresponse IRTs were short (Bin 1) than the proportion of postshock IRTs which were short. A large proportion of the postshock IRTs were greater than 2.0 sec.

Figure 6 provides the means for each of the first 10 IRTs after shock averaged over the last five sessions of a given condition. The "ascending" columns refer to the series of conditions in which the VR punishment schedule value was increased from VR10 to VR800. The "descending" column refers to the sequence from VR400 to VR10. Although the first IRT after shock tends to be longer than subsequent IRTs, no consistent change in the shape of these curves can be detected as a function of VR punishment schedule value. Beyond the 10th response after shock (not shown) no consistent trend in mean IRT is apparent.

DISCUSSION

Although for 5 of 12 subjects the overall rate of responding decreased as a function of the intensity of VR10 punishment shock, this was not the case for the other subjects. For those subjects, the overall response rate increased over the previously unpunished baseline for one or more shock intensity conditions. This response-rate facilitation has previously been observed during intermittently scheduled response-contingent shock, when the shock schedule was fixed-interval (Appel, 1968), variable-interval (Filby & Appel, 1966), fixed-ratio (Sandler, 1964), or random-ratio (Snapper et al., 1966), and especially for relatively low shock intensities. In order to more closely evaluate response rate facilitation in the pres-

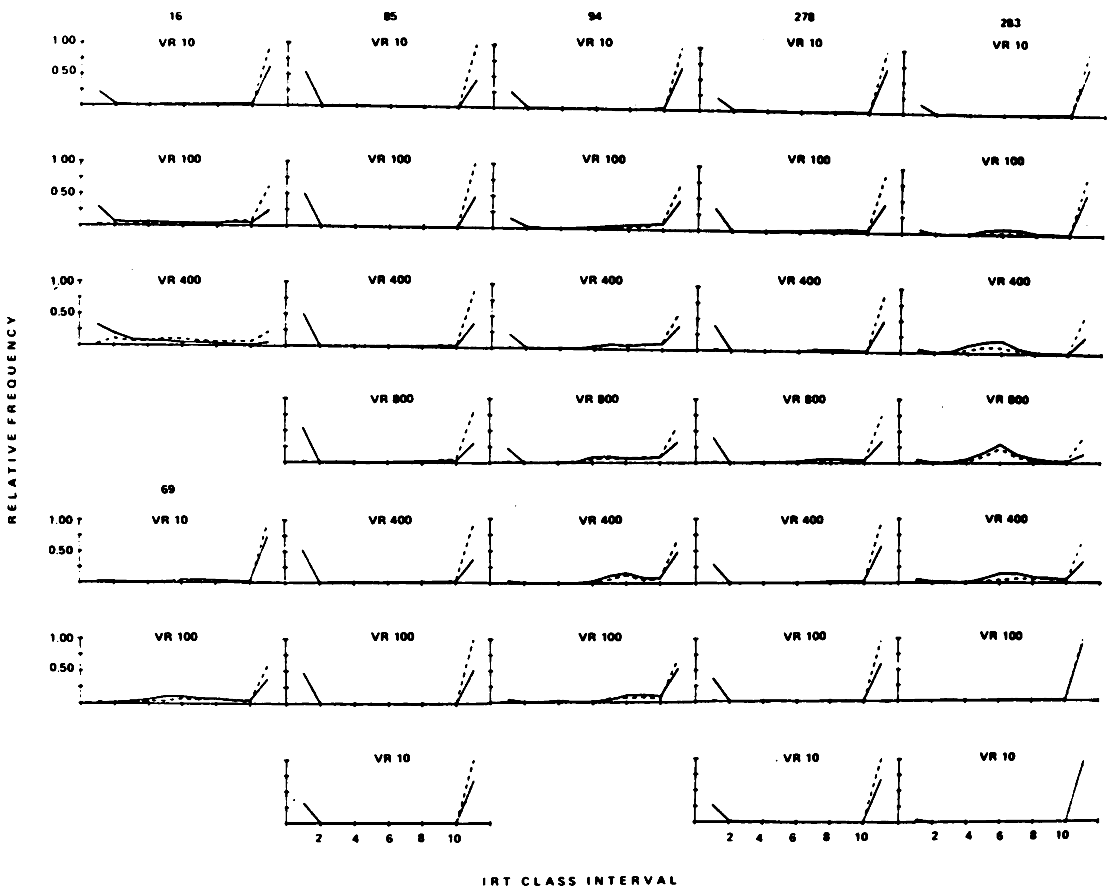

Fig. 5. The mean relative frequency for overall IRTs (solid lines) and reinforced IRTs (dashed lines) averaged over the last five sessions of exposure to each VR punishment schedule, by subject. The IRT class interval bin-width is equal to .20 sec with all IRTs greater than 2.0 sec represented in the 11th IRT class interval.

ent experiment, consider first the overall IRT distributions during VR10 punishment. During VR10 punishment, increasing the shock intensity increased the relative frequency of very short overall IRTs (less than .20 sec) and long overall IRTs (greater than 2 sec). It appears that response rate facilitation occurred when the relative frequency of very short IRTs increased over or more rapidly than the relative frequency of long IRTs.

In contrast, overall response rate was directly related to mean VR punishment ratio for all subjects. These results are similar to those obtained when the ratio value was varied during FR punishment (Azrin, Holz, & Hake, 1963). In the present experiment, the relative frequency of long IRTs increased as a function of scheduled punishment frequency. The frequency of very short IRTs was unrelated to the mean VR value. Thus, the increased relative frequency of long IRTs at higher scheduled VR punishment frequencies accounts for the decreased overall response rate.

Some of the present data can be related to IRT data collected in the study of reinforcement. The present study demonstrated that the introduction of VR punishment produced a greater relative frequency of very short (i.e., less than .20 sec) IRTs than that obtained during unpunished baseline. These very short IRTs or response bursts were maintained even though they were infrequently reinforced. In the study of reinforcement, a variety of operations have also been shown to maintain a high relative frequency of very short IRTs in the absence of reinforcement for those IRTs (e.g., Anger, 1956; Blough, 1963, 1966; Bruner, 1967; Conrad, Sidman, & Herrnstein, 1958; Malott

Table 4

The mean relative frequency for postshock and postresponse IRTs in IRT class intervals 1 (.0 to .2 sec) and 11 (greater than 2.0 sec) by subject for each VR punishment schedule.

Punishment Schedule VR	16: 1	16: 11	69: 1	69: 11	85: 1	85: 11	94: 1	94: 11	278: 1	278: 11	283: 1	283: 11
Postshock IRTs (mean relative frequency)												
10	.075	.815	.000	.975	.394	.606	.005	.971	.030	.962	.069	.931
100	.147	.322	.000	.857	.072	.928	.000	1.00	.000	1.00	.000	1.00
400	.215	.079			.113	.846	.000	1.00	.000	1.00	.000	.893
800					.200	.800	.000	1.00	.125	.875	.000	1.00
400					.433	.567	.000	1.00	.000	1.00	.000	1.00
100					.480	.520	.000	1.00	.063	.937	.000	1.00
10					.315	.685			.058	.942	.061	.939
Postresponse IRTs (mean relative frequency)												
10	.227	.609	.026	.711	.561	.421	.290	.630	.227	.667	.159	.741
100	.299	.240	.009	.371	.514	.477	.153	.449	.353	.439	.065	.633
400	.323	.057			.508	.378	.224	.375	.394	.491	.061	.268
800					.544	.312	.228	.327	.405	.336	.057	.139
400					.522	.367	.037	.474	.303	.584	.055	.328
100					.470	.516	.047	.523	.369	.591	.009	.914
10					.320	.674			.290	.651	.038	.951

& Cumming, 1964a, 1966; Staddon, 1965). For example, extinction after a period of exposure to VI reinforcement for key-peck responding increased the frequency of very short (about .1 sec) IRTs (Blough, 1963). Blough also showed that short IRTs were maintained during DRL 3.5-sec reinforcement, in the absence of reinforcement for short IRTs. Thus, very

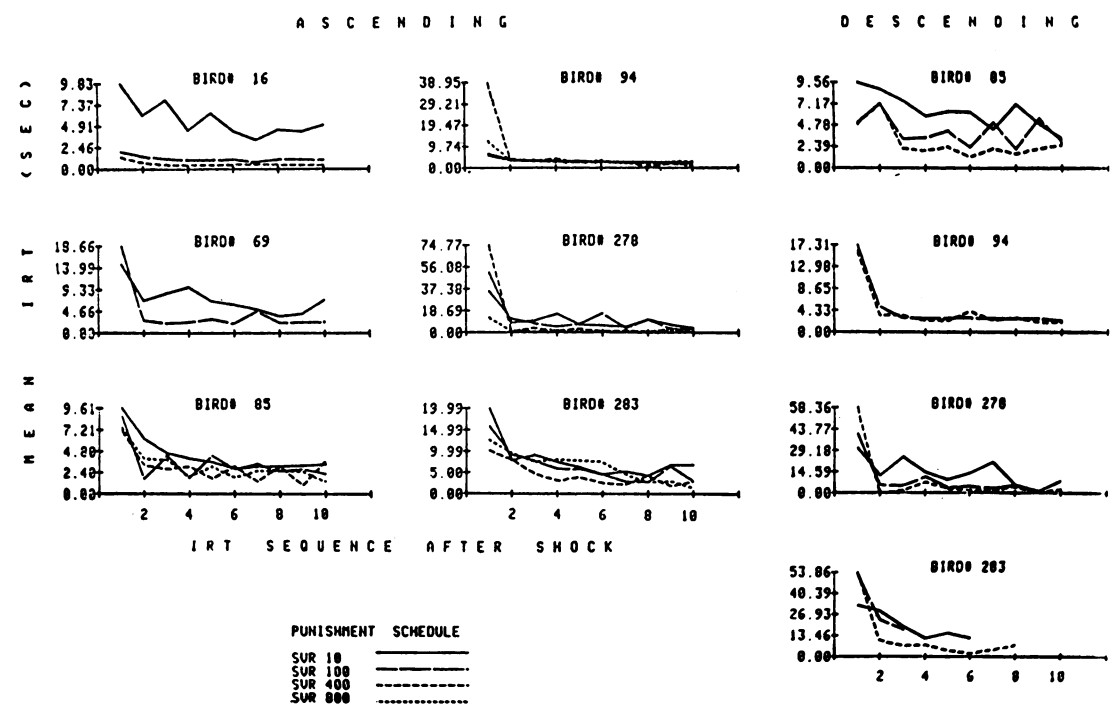

Fig. 6. The means (in seconds) for the first 10 IRTs after shock, by subject, averaged over the last five sessions of exposure to each VR punishment schedule. The ordinate differs for each subject.

short IRTs were not maintained by reinforcement contingencies.

Blough (1966) suggested that these very short IRTs were produced by a change in key-peck topography coinciding with certain manipulations. That is, a change in response topography was thought to be responsible for the recording of double key pecks as two separate responses, or one very short IRT. Thus, very short IRTs were considered an annoying source of increased variability, rather than a subject of study. In fact, several studies have employed mechanical procedures to eliminate short IRTs (e.g., Shimp, 1967; 1968; Staddon, 1968). In contrast, the present study underscores the importance of very short IRTs in modulating the direction of VR punishment effects. For example, increases in the frequency of very short IRTs accounted for instances of response rate facilitation during VR10 punishment.

The relatively high frequency of very short IRTs produced by and maintained throughout VR punishment shock exhibits some of the characteristics of elicited behavior. First, electric shock has been shown to elicit behavior that tends to increase at higher intensities of shock (e.g., Campbell & Teghtsoonian, 1958; Fowler & Miller, 1963; Goodman, Dyal, Zinser, & Golub, 1966). In the present study, increasing the intensity of VR10 punishment shock increased the relative frequency of very short IRTs. Thus, the increased relative frequency of very short IRTs may be considered elicited behavior. Further, runway performance has previously been shown to be facilitated by shock when the elicited behavior was compatible with running (Fowler & Miller, 1963). That is, shock elicited a lurching response which increased overall running speed. Thus, in the present experiment, VR scheduled shock may be said to elicit some behavior which is compatible with key-peck responding. Yet, it is unlikely that the elicited behavior resulted in a change in key-peck topography which became more compatible with responding at increased shock intensities.

Assuming in the present study that the high relative frequency of very short IRTs during VR-scheduled shock reflected elicited behavior, the eliciting stimulus is in question. If the elicited behavior only occurred immediately after shock presentations, and without any reinforcing consequence, that behavior may be considered an unconditioned response. Yet, in the present experiment, very short IRTs occurred to a greater extent during periods not initiated by shock. One possible interpretation of response bursting is that it is developed and maintained as a by-product of intermittent shock presentation. For example, previous research has shown that bar-press responding in monkeys could be maintained under an FI schedule of shock presentation. In one study (McKearney, 1969), the rate of responding was directly related to shock intensity and inversely related to scheduled FI shock frequency. The present study has also shown that bursting increased with shock intensity, but no relation to scheduled shock frequency was revealed.

The presentation of shock also suppresses responding for a period of time. In the present study, the mean postshock IRT and the next several IRTs following shock tended to be longer than subsequent IRTs. In addition, the mean postshock IRT was greater than subsequent IRTs, even in cases where the response rate was greater than the previously unpunished baseline. A similar result was reported by Snapper, Schoenfeld, and Locke (1966). Further, the postshock IRT was directly related to shock intensity but not shock frequency. These results are consistent with the observation that shock, especially at higher intensities, may elicit behavior that is incompatible with responding (Fowler & Miller, 1963). Further, the mean for the first several IRTs following shock was inversely related to the position in the sequence of these IRTs. That is, the running response rate increased for the first several responses after shock. This observation is consistent with a previous study which demonstrated that shock-elicited behavior which is incompatible with key-peck responding diminishes within a short time after shock presentation (Smith, Gustavson, & Gregor, 1972).

IMPLICATIONS FOR A THEORY OF PUNISHMENT

Theories of punishment have attempted to explain the suppression of punished responding on the basis of alternative or competing responses generated by the punishment process. The general form of this theory states that a decrement in the frequency of a punished response is a result of an increment in the frequency of behavior which is incompatible with the punished response.

Current versions of punishment theory (cf. Dunham, 1971, Rescorla & Solomon, 1967) outline two processes involved in punishment. First, the punisher elicits reflexive behavior which interferes with punished responding. Bolles (1967) states that this may be withdrawal, cowering, startle, or fear. The punisher is associated with a variety of stimuli that become conditioned punishers. Conditioned punishers should also elicit these reflexive behaviors (and fear). These conditioned punishers are assumed to be environmental cues, as well as proprioceptive stimuli associated with responding which precedes shock. Second, alternative responses are said to result in the termination or avoidance of fear and conditioned punishers. Thus, alternative responses might be negatively reinforced (Dinsmoor, 1954, 1977). For example, turning toward the rear of a pigeon's experimental chamber should be strengthened because it successfully avoids stimuli associated with punished key pecking.

It is clear that shock may elicit behavior that is incompatible with punished responding (e.g., Fowler & Miller, 1963; Smith et al., 1972). For example, shock can be seen to elicit wing flapping and withdrawal in the pigeon. The extent of this behavior can be seen in the present study by the decrease in mean IRT over the first few responses after shock. After the first several IRTs, the mean IRT reached an asymptotic value. Higher intensities of shock not only increased the means for each of the first several IRTs after shock, but also increased the total time until the asymptote was reached. This may be interpreted to indicate that the duration of shock elicited behavior incompatible with key pecking increased as a function of shock intensity.

In contrast, unpunished periods were characterized by response bursting (i.e., very short IRTs) and longer IRTs. During the pauses between response bursts, spinning or sitting was often observed. These types of behavior appear similar to overt mediating behaviors seen during DRL performance (e.g., Hodos, Ross, & Brady, 1962; Laties, Weiss, Clark, & Reynolds, 1965). It is possible that just as those activities are positively reinforced on DRL, similar behavior may be negatively reinforced by predicting longer shock-free periods during punishment (Dunham, 1971).

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Received June 5, 1979
Final acceptance July 14, 1980