SCHEDULE INTERACTIONS INVOLVING PUNISHMENT WITH PIGEONS AND HUMANS

JOHN CROSBIE, APRIL MICHELE WILLIAMS, KENNON A. LATTAL, MICHELLE M. ANDERSON, AND SUZANNE M. BROWN

WEST VIRGINIA UNIVERSITY AND
DEAKIN UNIVERSITY, GEELONG, AUSTRALIA

The principal aim of the present experiments was to assess whether punishment increased or decreased the rate of unpunished behavior (contrast and induction, respectively) for which reinforcement rate was held constant, with physical and nonphysical punishers (electric shock and response cost), pigeon and human subjects, signaled and unsignaled components (multiple and mixed schedules), and the presence or absence of a blackout period between components. Across the three experiments there were 20 punishment conditions. Induction was found in nine of those, less consistent response-rate reduction was found in three, contrast was found in four, and in four there was no change in responding from conditions without punishment. Contrast occurred consistently only with multiple schedules during the first exposure to electric-shock punishment. Induction and no change, however, were found with every combination of the independent variables studied. Four conclusions regarding the interactions between punished and unpunished responding emerged from the present results: (a) Both contrast and induction occurred with the reinforcement rate held constant and a blackout between components, (b) induction was more common than contrast, (c) contrast occurred only in the presence of a stimulus different from that correlated with the punisher, and (d) contrast diminished with prolonged exposure to punishment. None of the current theoretical accounts of punishment contrast can explain the present results.

Key words: punishment, electric shock, response cost, key peck, lever press, pigeons, humans

---

The effects of different parameters of punishment have been investigated extensively (e.g., Azrin & Holz, 1966; Baron, 1991; Crosbie, in press), but less is known about the effects of punishment on unpunished responses. Punishment can leave unpunished responses unchanged, or it can increase or decrease the rate of such responses relative to their rates before the punishment condition.

The present research was supported by grants from the Eberly College of Arts and Sciences, West Virginia University, and the Deakin University research budget.

Multiple-schedule results for Experiment 1 were presented at the 1992 meeting of the Association for Behavior Analysis in San Francisco; mixed-schedule results for Experiment 1 were presented at the 1993 meeting of the Southeastern Association for Behavior Analysis in Chapel Hill, North Carolina; Experiments 2 and 3 were presented at the 1994 meeting of the Association for Behavior Analysis in Atlanta, Georgia; Experiments 1 (mixed-schedule results) and 2 were reported in a Masters thesis by Michele Williams, and portions of Experiment 3 were reported in an honors thesis by Suzanne Brown.

We are grateful to Natalie Staats for helping to collect data for Experiment 3, and to Jennifer O'Donnell for providing helpful comments on an earlier version of this manuscript.

Correspondence concerning this article should be sent to John Crosbie, Department of Psychology, West Virginia University, Morgantown, West Virginia 26506-6040 (E-mail: jcrosbie@wvu.edu).

Punishment effects on unpunished responses have been studied in three main ways. First, a single response was punished for many sessions, and, when punishment ceased, there were transient increases in responding relative to prepunishment rates (Azrin & Holz, 1966). Second, responding was punished in the presence of only one of seven wavelengths of light, and response rates were suppressed in the presence of each wavelength as a function of the physical similarity between that wavelength and the one correlated with punishment (Honig & Slivka, 1964). With the third method, responding was punished in only one component of a two-component multiple schedule. In keeping with other types of behavior interactions in multiple-schedule components, increases and decreases in rates of unpunished responses have been labeled *punishment contrast* and *punishment induction,* respectively (cf. Reynolds, 1961a). The multiple-schedule method has been used most frequently to study the effects of punishment on unpunished responding because, unlike the first procedure used by Azrin and colleagues, it permits continued exposure to punishment, and it is easier to arrange than Honig and Slivka's procedure.

It is not clear which variables determine whether contrast, induction, or neither occurs when responses in one component of a multiple schedule are punished. For example, Azrin and Holz (1966, p. 417) punished each response in one component of a two-component multiple variable-interval (VI) VI schedule. Responding was completely suppressed in both components for the first 10 sessions; then, response rates in the component not correlated with punishment returned to their levels before the punishment condition. Over the next few sessions, response rates in the punishment component recovered slowly. Eventually response rates in the no-punishment component were higher than those during the condition before punishment was introduced. Thus, what began as an induction effect of punishment ultimately became a contrast effect. This analysis, however, was based on the published record of a single subject, and both the reliability and generality of the finding may be questioned. In a more thorough experimental analysis, Brethower and Reynolds (1962) arranged punishment in only one component of a multiple VI VI schedule and found variable responding across and within subjects in the component uncorrelated with punishment. Controlling variables are difficult to isolate, however, because conditions were in effect for varying periods of time, punishment intensities were changed irregularly, and, under different conditions, the same intensity of punishment produced contrast and induction. Consequently, there was little evidence of a systematic relation between punishment intensity and rate of unpunished responding. Rachlin (1966) also presented electric shock after every response in one component of a multiple VI VI schedule, but found no consistent effects on responding in the other component. His findings are limited, however, because he used only a mild shock, which over time did not suppress responding, and consequently cannot be considered functionally to be a punisher.

Although the multiple-schedule procedure described above is a useful way to study punishment effects on unpunished responding, it can produce results that are difficult to interpret. Two potential problems are uncontrolled reinforcement rate and accidental correlations between responding and discriminative stimuli. Reducing the rate of reinforcement in one component of a multiple schedule increases response rate in the unchanged component (Mackintosh, 1974; Reynolds, 1961b). When a punisher suppresses responding in a multiple-schedule component to the extent that there is a systematic reduction in the rate of reinforcement, changes in unpunished responding cannot be attributed simply and directly to punishment. Two ways to avoid that problem are to arrange reinforcement on a VI schedule so that virtually all programmed reinforcers are obtained even if response rates are low, and to slowly increase the punisher magnitude until criterion suppression (e.g., less than 50% of baseline rate) is achieved. When multiple-schedule components alternate, it is possible for responding in one component to be maintained in part by accidental correlations between responding in that component and the change to the next component (e.g., Morse & Skinner, 1957). If unpunished responses are correlated with the onset of a discriminative stimulus correlated with punishment, those responses also may be suppressed (Hoffman & Fleshler, 1965). One way to minimize such accidental correlations is to impose a blackout between the components.

The extant literature on the effects of punishment on unpunished responses raises more questions than it answers. Hence, the present experiments were designed to explore these effects further. The work of Azrin and Holz (1966) and of Brethower and Reynolds (1962) suggests that the nature of schedule interactions involving punishment may change with repeated exposure to punishment, but their experiments do not offer a satisfactory test of that possibility. Azrin and Holz reported data from only one condition and 1 subject, and Brethower and Reynolds' procedure confounded successive exposure to punishment with changes in shock intensity. The time course of schedule interactions involving punishment both within and between conditions was examined in our first experiment. Following Honig and Slivka's (1964) work, the contributions of discriminative stimuli to schedule interactions involving punishment were examined in the present Experiments 1 and 2. The effects of blackouts on multiple-schedule interactions have not been assessed systematically. For the reasons described above, the presence or absence of a blackout in multiple schedules that involve punishment may influence the degree or even type of schedule interaction. For that reason, a comparison of interactions in multiple schedules with and without blackouts between components was included in Experiment 1. Finally, the effects of punishment on unpunished responding have been studied almost exclusively using electric shock as the punisher. Such interactions have been studied in rats (e.g., Tullis & Walters, 1968), pigeons (e.g., Brethower & Reynolds, 1962), and monkeys (Lattal & Griffin, 1972), but rarely in humans. To extend the generality of our analysis, in Experiment 3 the responding of humans in one multiple-schedule component was punished by loss of accumulated reinforcers (response cost) to assess the effects on responding in the other component.

EXPERIMENT 1

In this experiment the time course of schedule interactions between punished and unpunished behavior was examined while punishment intensity and reinforcement rate were held constant. In addition, the effects on such interactions of both blackouts between components and component discriminative stimuli were also examined.

METHOD

Subjects

Four adult male White Carneau pigeons with no prior experimental history were maintained at approximately 80% of their free-feeding weights.

Apparatus

An experimental chamber with dimensions of 33.5 cm by 30.0 cm by 31.5 cm was used. Walls were made of Plexiglas except for the aluminum work panel, and the chamber was enclosed in a wooden box with a fan that provided ventilation and masking noise. The hopper aperture (4.5 cm by 6.0 cm) was located in the middle of the work panel, 7.5 cm from the floor. Reinforcement was 3-s access to mixed grain. The response key (2.3 cm in diameter, located 24 cm from the floor and 5 cm from the right wall of the chamber) could be transilluminated by a yellow or blue bulb, and was operated by a force of 0.15 N. General illumination was provided at all times (except during delivery of reinforcers) by a 24-V houselight located in the upper right corner of the work panel. Electric shock was delivered through electrodes implanted around a subject's pubis bones as described by Azrin (1959). Electrodes were connected to a plug attached to a leather shock jacket that each bird wore throughout the experiment. The jacket plug was attached to a mercury-based commutator (located outside the chamber) that was attached to an AC shock generator. The experiment was controlled by an IBM® PC-compatible computer running MEDPC® software. Control and recording equipment was located in an adjoining room.

Procedure

The key-peck response first was shaped through differential reinforcement of successive approximations. Shaping was followed by one or two sessions in which a reinforcer followed every response, a few sessions in which a fixed number of responses was required to obtain reinforcement with the ratio requirement increased each session, and several sessions in which reinforcement was provided on a VI schedule. The VI value was increased slowly from 5 s to a final value of 3 min. When consistent responding was obtained on VI 3 min, a multiple VI 3-min VI 3-min schedule was introduced. Table 1 provides the sequence of conditions and the number of sessions of each for each subject.

A multiple schedule operated during the first five conditions of the experiment. The response key was illuminated alternately by the yellow or blue light for 2 min each. Each color was presented 15 times per session. For 2 subjects (P2307 and P4894) there was a 2-s blackout between components (i.e., all lights were extinguished and pecking had no programmed consequences); for the other 2 subjects (P2348 and P2118) there was no blackout between components. Reinforcers were delivered in each component according to independent VI 3-min schedules (produced from 10 terms of a Fleshler & Hoffman, 1962, series). The VI interreinforcer-interval timer for a component stopped when that component was not in operation. Reinforcers sched-

Table 1

Experiment 1: Sequence of conditions, the number of sessions in each, and final electric shock intensity (mA) for the stable sessions of each condition without punishment ($\bar{P}$) and the final 10 sessions of each condition with punishment (P). Mean responses per minute and mean reinforcers per hour are also shown for multiple-schedule (MULT) and mixed-schedule (MIX) Components A and B.

Subject	Condition	Schedule	Sessions	Shock (mA)	Response rate		Reinforcement rate	
					A	B	A	B
P2307	$\bar{P}$	MULT	24		34.93	32.90	16.34	16.78
	P	MULT	29	6	53.92	9.83	17.24	17.80
	$\bar{P}$	MULT	48		51.21	41.09	17.80	17.66
	P	MULT	22	4	43.50	2.69	17.56	16.28
	$\bar{P}$	MULT	17		55.52	56.66	17.38	17.50
	$\bar{P}$	MIX	9		70.07	70.95	15.59	15.71
	P	MIX	33	5	46.51	7.26	15.73	14.04
	$\bar{P}$	MIX	6		45.27	44.22	15.90	16.00
P4894	$\bar{P}$	MULT	29		29.36	28.34	16.90	16.68
	P	MULT	18	4	38.33	7.67	17.66	16.88
	$\bar{P}$	MULT	25		37.62	37.12	17.12	17.12
	P	MULT	13	2	16.59	5.80	14.46	14.00
	$\bar{P}$	MULT	18		40.37	37.49	17.34	18.00
	$\bar{P}$	MIX	6		37.25	38.41	15.90	15.11
	P	MIX	18	3	29.07	10.06	15.53	14.76
	$\bar{P}$	MIX	6		39.12	39.37	15.30	15.70
P2348	$\bar{P}$	MULT	43		51.31	43.48	17.82	17.82
	P	MULT	24	8	47.91	18.87	18.70	18.34
	$\bar{P}$	MULT	32		42.10	34.12	17.80	17.36
	P	MULT	22	6	39.90	11.68	17.64	17.28
	$\bar{P}$	MULT	16		35.33	31.48	17.76	17.38
	$\bar{P}$	MIX	8		46.19	47.61	17.67	17.67
	P	MIX	27	6	33.35	18.49	17.80	17.40
	$\bar{P}$	MIX	6		42.19	43.16	17.00	18.00
P2118	$\bar{P}$	MULT	23		59.78	62.11	17.30	17.66
	P	MULT	23	7	92.78	29.24	17.56	17.80
	$\bar{P}$	MULT	20		75.17	81.50	18.00	17.90
	P	MULT	23	4	38.22	25.92	16.88	17.30
	$\bar{P}$	MULT	16		65.05	63.08	17.24	17.62

Note. During MULT conditions, Components A and B were correlated with yellow and blue keylights, respectively. During MIX conditions, Components A and B were both correlated with yellow keylights. During P conditions, every response in Component B was punished with electric shock of the intensity shown; during $\bar{P}$ conditions, no response was punished.

uled but not collected were held until components changed.

After responding had stabilized in both components (i.e., there were six consecutive sessions in which there was no apparent increasing or decreasing trend and mean response rates of the first and last three-session blocks differed by less than ±5% from the overall mean of the six), electric shock was introduced following each response in the component correlated with the blue light. Shock duration was 50 ms. The initial shock intensity was 0.8 mA and was increased in 0.4-mA increments per session, at the beginning of each session, until responding in the punishment component was less than 50% of its rate during the preceding condition without punishment for 10 consecutive sessions with shock intensity held constant. Shock then was discontinued, and responding in both components was allowed to stabilize. Following this, punishment was reinstated with the procedure described above. There were two conditions in which shock was presented in the component correlated with the blue light and three conditions in which shock was not presented in either component.

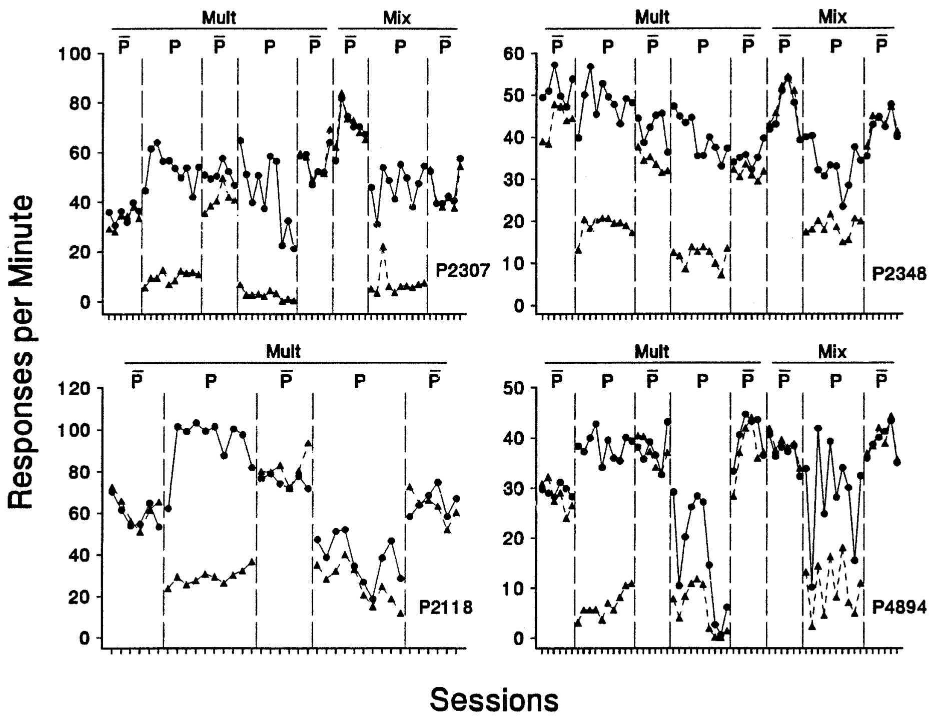

Fig. 1. Experiment 1: Response rate in each component during the stable sessions of conditions without punishment ($\bar{P}$) and the final 10 sessions of conditions with punishment (P). Circles show the component in which responding was never punished; triangles show the component in which every response was punished during P. During the first five conditions a multiple schedule operated (i.e., circle and triangle components were correlated with yellow and blue lights, respectively). During the last three conditions a mixed schedule operated (i.e., circle and triangle components were both correlated with yellow lights). For P2307 and P4894, there was a 2-s blackout between components; for P2348 and P2118, there was no blackout.

During the next three conditions a mixed schedule was in effect. The keylight was yellow in both components. After responding had stabilized in both components of the mixed VI 3-min VI 3-min schedule according to the stability criteria described above, electric shock followed each peck in one component, hereafter described as the punishment component. As with the multiple schedule, shock intensity began at 0.8 mA and increased in 0.4-mA increments per session until responding in the punishment component was less than 50% of its rate during the preceding condition without punishment for 10 consecutive sessions with shock intensity held constant. Shock then was discontinued. With the mixed schedule, there was one condition in which shock was presented in one component and two conditions in which shock was not presented (see Table 1). As with the multiple schedule, P2307 and P4894 received a 2-s blackout between components, and P2348 did not. Pigeon P2118 did not complete the mixed-schedule portion of the experiment.

Results

Table 1 shows response and reinforcement rates in each component during each condition of the experiment. Across conditions, reinforcement rate remained relatively constant. Hence, response-rate changes in the no-punishment component (A) were not caused by systematic changes in reinforcement rate.

Figure 1 shows response rate in each component for the stable sessions of each condition without punishment ($\bar{P}$) and the last 10 sessions of each condition with punishment (P). For all subjects there was evidence of punishment (i.e., response suppression) during all three punishment conditions (triangles during P). Table 1 also shows the final shock intensity for each punishment condition. Note that less intense shock was required to achieve the suppression criterion during the second punishment condition on a multiple schedule (this was also found by Rachlin, 1966), and that the suppression criterion was achieved in the mixed schedule with a shock intensity between that required to achieve the suppression criterion on the multiple schedules (2 birds) or equal to that of the second punishment condition (1 bird).

On the multiple schedule, the responding of P2348 was different from that of the other subjects in that punishment had no effect on unpunished responding, which decreased consistently across the five conditions (circles in the top right panel of Figure 1). The other 3 subjects, however, exhibited the same general pattern of contrast in the first punishment condition and induction in the second punishment condition.

Although there was a large consistent increase in response rate from the first condition without punishment to the first punishment condition for 3 subjects, for only 1 subject (P2118) was there decreased responding when punishment ceased. This suggests that the behavior of P2307 and P4894 was merely in transition to a higher rate during the punishment condition, as opposed to demonstrating true contrast. This explanation seems unlikely, however, because the first condition without punishment continued for many sessions (see Table 1), and responding satisfied visual and statistical stability criteria. Only when punishment was introduced was there an abrupt increase in response rate, and that increase was maintained. That there was no reduction when punishment was discontinued is less than perfect evidence of contrast, but the initial increases seem to be sufficiently large and consistent to qualify as punishment contrast. Punishment contrast was found despite a constant reinforcement rate across conditions, and even though shock intensity was increased slowly over several sessions.

For 2 of the 3 subjects that showed contrast during the first punishment condition (P2118 and P4894), there was evidence of induction during the second punishment condition. For P2307 there was a decreasing downward trend in response rate during the second punishment condition, but there was too much overlap with the response rates in the previous and subsequent conditions without punishment to label the response-rate decrease as punishment induction.

Under the mixed schedule, induction occurred for P2307 and P2348. For P4894, however, although response rate during several sessions in the punishment condition was lower than in the conditions without punishment, there was too much overlap between conditions with and without punishment to label this effect as punishment induction. As was found with the multiple schedule, response rate rarely increased to prepunishment levels when punishment was discontinued.

There were no systematic differences in responding for the subjects that received a blackout (P2307 and P4894) and those that did not (P2348 and P2118). Both pairs of subjects showed some evidence of contrast during the first punishment condition and induction during subsequent exposures to punishment. This result suggests that (a) accidental correlations between responding in one component and the change to the next component cannot explain contrast and induction, and (b) blackouts may not be required when studying schedule interactions.

EXPERIMENT 2

In Experiment 1, schedule interactions were similar during the second punishment condition arranged on a multiple schedule and during the subsequent punishment condition arranged on a mixed schedule. These results suggest that such interactions are unaffected by the presence or absence of discriminative stimuli correlated with punishment. Such a conclusion cannot be drawn unequivocally from the results of that experiment, however, because all subjects received the punishment condition arranged on a mixed schedule after two punishment conditions arranged on a multiple schedule, and condition order may have affected interactions. For example, with the multiple schedule, contrast was found during the first punishment condition, but induction was found with the second punishment condition. The aim of the second experiment was to provide an additional test of the role of discriminative stimuli in schedule interactions that involve punishment. In this experiment, experimentally naive pigeons were used to control for possible effects related to prior punishment that might have confounded the outcome of the multiple mixed-schedule comparisons in the first experiment. To control for potential differences in schedule interactions that may have resulted from the sequence of stimulus conditions, a three-component schedule was arranged in which the punishment component was followed equally often by either of two components in which punishment did not occur. One no-punishment component was correlated with the same stimulus that was used in the component in which responses were punished, and the other no-punishment component was correlated with a different stimulus.

Method

Subjects

Three experimentally naive adult male White Carneau pigeons were maintained at approximately 80% of their free-feeding weights.

Apparatus

The apparatus was identical to that used in Experiment 1, except for the following changes. A standard experimental chamber with dimensions of 30.0 cm by 37.5 cm by 31.0 cm was used. Walls were made of wood instead of Plexiglas, except for the metal work panel. The hopper aperture (6 cm by 5 cm) was located in the middle of the work panel, 7 cm from the floor and 13 cm from the right wall. The response key was located 22 cm from the floor and 7 cm from the right wall, was transilluminated by a white or green bulb, and could be operated with a force of 0.15 N.

Procedure

Training was as described in Experiment 1. When subjects responded reliably on a VI 3-min schedule on a single key, they were exposed to a three-component schedule in which each component was presented for 2 min, during which an independent VI 3-min schedule was in effect. Components were presented in the following sequence: A (white key), then B (green key) or C (white key) determined randomly with p = .5, then A. Each session was composed of 14 presentations of A, seven presentations of B, and seven presentations of C. There were no blackouts between components.

When responding in each component was stable according to the same stability criteria employed in Experiment 1, shock was presented after every response in Component A. Hereafter Component A is described as the punishment component, and Components B and C are described as no-punishment components. Shock duration was 50 ms. Shock intensity was 0.8 mA during the first session and was increased in 0.4-mA increments per session until responding in Component A was less than 50% of its prepunishment rate for 20 consecutive sessions at the same shock intensity. Shock was then removed and the experiment continued until responding in each component stabilized. Table 2 provides the sequence of conditions and the number of sessions of each for each subject.

Results

Table 2 also shows response and reinforcement rates in each component of each condition. Within each condition, reinforcement rate was similar in each component. Reinforcement rate decreased slightly during the punishment condition, but such a modest change cannot explain the large changes in response rate during that condition.

Figure 2 shows response rate in each component during the stable sessions of each condition without punishment ($\overline{P}$) and during the final 20 sessions of the punishment condition (P). All subjects showed evidence of punishment. Table 2 shows the shock intensity that produced criterion suppression for each punishment condition.

For 2 subjects (P2617 and P3895) responding in both no-punishment components decreased during the punishment condition then increased when punishment ceased. Furthermore, no-punishment components had similar response rates during the punishment condition. Thus, for these 2 subjects, discriminative stimuli did not affect unpunished responding, and the effect was induction. For these subjects, induction was found during the first exposure to punishment.

For the other subject (P1666), however, there was a difference in response rates between no-punishment components. In the no-punishment component correlated with a different key color from that correlated with

Table 2

Experiment 2: Sequence of conditions, the number of sessions in each, and final electric shock intensity (mA) for the stable sessions of each condition without punishment ($\overline{P}$) and the final 20 sessions of each condition with punishment (P). Mean responses per minute and mean reinforcers per hour are also shown for Components A, B, and C.

Subject	Condition	Sessions	Shock (mA)	Response rate A	Response rate B	Response rate C	Reinforcement rate A	Reinforcement rate B	Reinforcement rate C
P2617	$\overline{P}$	6		32.21	27.69	34.13	18.27	17.53	18.96
	P	26	2	2.34	7.13	5.25	13.55	10.59	13.31
	$\overline{P}$	12		32.41	29.45	33.71	18.62	16.88	16.88
P3895	$\overline{P}$	15		32.66	29.95	32.59	16.88	16.88	16.88
	P	34	4	0.91	15.11	12.29	13.31	13.31	13.31
	$\overline{P}$	10		49.12	33.46	49.46	16.88	16.88	16.88
P1666	$\overline{P}$	28		25.47	18.83	24.29	16.88	16.88	16.88
	P	30	3	5.69	35.59	25.19	13.31	13.31	13.31
	$\overline{P}$	10		28.06	24.66	25.73	16.88	16.88	16.88

Note. Component A was correlated with a white key color, and during P every response was punished with electric shock of the intensity shown. Component B was correlated with a green key color, and no response was punished. Component C was correlated with a white key color, and no response was punished.

punishment, responding increased during the punishment condition and decreased when punishment ceased. In the no-punishment component correlated with the same key color as that correlated with punishment, there was no systematic change in responding between conditions with and without punishment. Thus, discriminative stimuli affected results, and there was evidence of contrast in the presence of a key color different from that correlated with punishment.

EXPERIMENT 3

This experiment was a systematic replication of Experiment 1 to assess whether punishment contrast and induction are also found with punishers other than electric shock. Human subjects pressed a lever for money, then each lever press also lost a portion of accumulated funds (i.e., response-cost punishment). Dynamic properties of punished and unpunished responses were also assessed to explore further the nature of punishment effects with humans.

Method

Subjects

One male (H31) and 2 female (H23 and H34) undergraduate students (aged 21 to 27 years) served as subjects. Subject H23 was at Deakin University; H31 and H34 were at West Virginia University. None had participated previously in operant studies. Subjects were paid according to their performance plus a $50 bonus for perfect attendance. If they missed any sessions the entire bonus was forfeited, and $5 was deducted from their total earnings for each session missed. Payment was in one lump sum at the end of the experiment. All monetary amounts are described in U.S. dollars.

Apparatus

Sessions were conducted in a section of a laboratory (180 cm by 200 cm) partitioned by portable room dividers. Figure 3 shows the arrangement of the apparatus. The subject sat at a desk equipped with an IBM® PC-compatible computer, a VGA color monitor, a mouse, and a response box. The response box had dimensions of 19 cm by 30 cm by 19 cm and contained a lever that was 2 cm in diameter, protruded 4.5 cm at 24° below horizontal, and was wrapped in spongy tennis racket grip. The lever was attached to a Lafayette Model 76613 force transducer that provided continuous readings of force up to 100 N with a precision of less than 1 N (see Crosbie, 1993, for further details).

For Subject H23, a response was recorded when force applied to the lever was more than 10 N for more than 50 ms then less than 10 N. A 50-ms minimum duration was sufficiently long to ensure that brief fluctuations around 10 N were not falsely recorded as re-

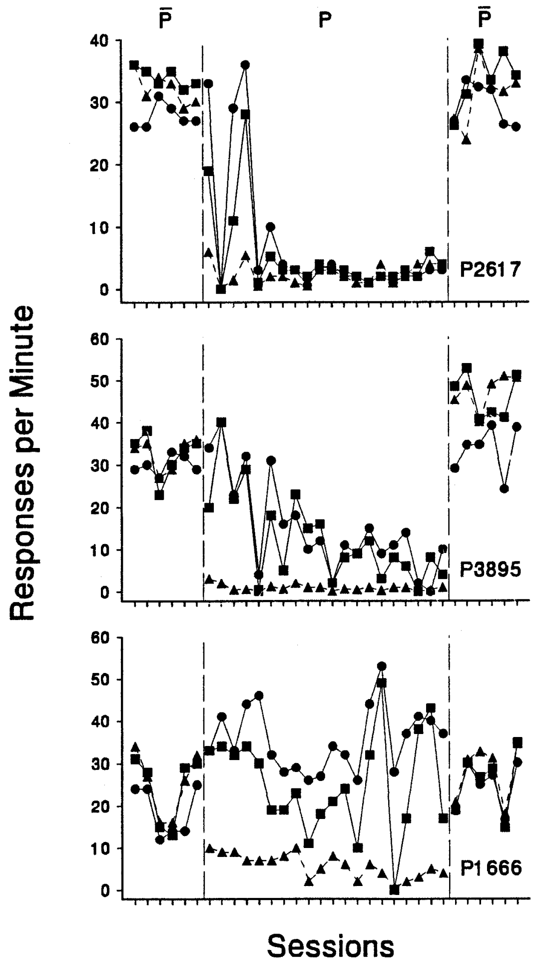

Fig. 2. Experiment 2: Response rate in each component during the stable sessions of conditions without punishment (P̄) and the final 20 sessions of the condition with punishment (P). Circles and squares show components in which responding was never punished; triangles show the component in which every response was punished during P. Square and triangle components were correlated with a white key; circle components were correlated with a green key. There was no blackout between components.

sponses. For Subjects H31 and H34, a response was recorded when force applied to the lever was more than 10 N then less than 3 N. This virtually complete release requirement also overcame potential recording problems with minor force fluctuations. For all subjects, only responses with a force over 30 N were eligible for reinforcement and punishment. Reinforcers and punishers were presented when responses terminated (i.e., when force was below 10 N for H23 and below 3 N for H31 and H34), in accord with previous investigations of response force (e.g., Fowler, 1987; Notterman & Mintz, 1965). For H23 there was no exteroceptive stimulus correlated with making a response, except when reinforcers and punishers were presented. For H31 and H34, each response with force greater than 30 N was followed by a brief click (100 Hz for 10 ms) when the response terminated.

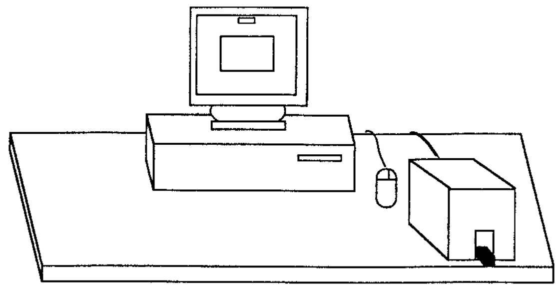

Fig. 3. Apparatus layout for Experiment 3.

When a reinforcer was presented, there was a 1,000-point increase in the subject's score (continuously displayed in a box at the top of the screen; 1,000 points were exchangeable for 40¢ for H23 and 25¢ for H31 and H34) plus a brief tone (1000 Hz for 100 ms). Subjects H31 and H34 also had a consummatory-response requirement (cf. Matthews, Shimoff, Catania, & Sagvolden, 1977). When a reinforcer was available, a white box (2.5 cm by 2.2 cm) was displayed in the top right corner of the computer screen for 5 s, and a mouse cursor was displayed at the bottom of the screen. If the subject moved the mouse cursor into the reinforcer box and pressed the left mouse button, 1,000 points were added to the total score, a 1000-Hz tone was presented for 100 ms, and the box and mouse cursor were removed from the screen. If a consummatory response was not made within 5 s, the box plus mouse cursor were removed from the screen, and no points were added to the score. Subjects needed to watch the screen to obtain reinforcers because the reinforcer box was presented with no accompanying sound. The punisher was a reduction in points (response cost) plus a brief tone (100 Hz for 300 ms). There was no consummatory-response requirement for punishment.

Red and green rectangles with dimensions

Table 3

Experiment 3: Sequence of conditions, the number of sessions in each, and final response-cost magnitude (RC) for the final eight sessions of each condition without punishment ($\overline{P}$) and the final 10 sessions of each condition with punishment (P). Mean responses per minute and mean reinforcers obtained per hour are also shown for multiple-schedule Components A and B.

Subject	Condition	Sessions	RC (points)	Response rate		Reinforcement rate	
				A	B	A	B
H23	$\overline{P}$	54		101.53	101.95	20.25	16.50
	P	20	9	107.31	1.42	18.60	16.80
	$\overline{P}$	15		90.24	89.19	24.00	22.50
H31	$\overline{P}$	16		228.58	232.94	34.89	34.72
	P	22	13	97.30	85.72	31.93	36.92
	$\overline{P}$	9		149.58	156.80	38.35	35.80
H34	$\overline{P}$	10		162.91	161.82	34.89	30.10
	P	14	9	107.33	16.32	28.84	26.63
	$\overline{P}$	47		87.81	85.27	28.09	30.78

Note: Components A and B were correlated with green and red rectangles, respectively. During P, every response in Component B was punished with response cost of the magnitude shown. During $\overline{P}$, no response was punished.

of 12.5 cm by 8.5 cm were presented in the center of the computer screen as discriminative stimuli.

Procedure

A multiple schedule was in effect in each session of the experiment. Table 3 shows the sequence of conditions and the number of sessions of each for each subject. A red or green rectangle was alternately displayed on the computer screen for 2 min each, with a 15-s blackout between rectangle presentations. Each color was presented five times per session. Training consisted of a few sessions in which a fixed (H23) or variable (H31 and H34) number of responses was required to obtain reinforcement (the ratio requirement was increased each session), and several sessions in which a VI schedule was in effect. Reinforcers were delivered in each component according to independent VI schedules (produced from 10 terms of a Fleshler & Hoffman, 1962, series). The VI timer for a component stopped when that component was not in operation, and reinforcers scheduled but not collected were held until components changed. The VI value in each component was increased slowly to a final value of 3 min for H23 and 2 min for H31 and H34.

After responding had stabilized in both components (i.e., there were eight sessions in which there was no apparent increasing or decreasing trend, mean response rates of the first and last four-session blocks differed by less than ±5% from the overall mean of the eight, and coefficients of variability and linearity were both less than .15; cf. Crosbie, in press; Killeen, 1978), points were lost after each response in the component correlated with the red rectangle. Response-cost magnitude was 1 point during the first session and was increased by approximately 1 point every session, at the beginning of the session, until responding in the punishment component was less than 50% of its prepunishment rate for 10 consecutive sessions with response-cost magnitude held constant. Response cost then was discontinued.

Before the first training session, subjects read the following instructions:

> In this experiment you will earn money by pressing and releasing the lever whenever a colored rectangle appears on the computer screen. Each colored rectangle will appear for two minutes. A blank screen will appear for 15 seconds between each presentation of a colored rectangle. When the screen is blank pressing the lever will have no effect. Sometimes when you press the lever you will win some points, and sometimes you will lose some points. Throughout the experiment your point score will be shown in the score box at the top of the screen. At the end of the experiment you will receive money based on the number of points in your score.

Subjects H31 and H34 were told that they would receive 25¢ for every 1,000 points, and H23 was told that she would receive 40¢ for every 1,000 points. Subjects H31 and H34 were also given a brief description of the consummatory-response requirement.

To standardize conditions and ensure that subjects could not time schedules, subjects left their watches outside the experimental area. They were told that metal on their hands or wrists would affect delicate equipment in the response box, and consequently they removed all metal jewelry before each session.

Each day, Monday to Friday, subjects participated for one 2-hr block of four 30-min sessions. During each session, subjects responded on the multiple schedule for 25 min, then had a 5-min break. Table 3 provides the sequence of conditions and the number of sessions of each for each subject.

RESULTS

Table 3 also shows response and obtained reinforcement rates in each component of each condition. Across conditions, obtained reinforcement rate remained relatively constant for all subjects. Net reinforcement (i.e., points obtained minus points lost) did not change significantly for H23 or H34, but fell dramatically for H31, given his relatively high rate of punished responding. Hence, response-rate changes in the no-punishment component (A) were not due in any systematic way to changes in reinforcement rate.

Because of a programming error, the punishment condition for H34 started before responding in the preceding condition was stable. Responding was stable, however, during the second condition without punishment for H34 and during both conditions without punishment for the other subjects. Figure 4 shows, for the last eight sessions of each condition without punishment ($\bar{P}$) and the last 10 sessions of the punishment condition (P), rate, peak force, and duration of functional responses (i.e., force greater than 30 N; top three rows), and the proportion of nonfunctional lever presses (force 10 N to 29 N; bottom row).

For all subjects, there was evidence of punishment (i.e., response rates in the punishment component were lower during P than during $\bar{P}$; triangles during P in top row of Figure 4). Table 3 also shows the response-cost magnitude that achieved criterion suppression. For the no-punishment component, during P there was induction for H31 and probably for H34 (unstable responding during the first $\bar{P}$ makes this conclusion tentative), and no change in responding for H23.

Although H23 and H34 made only a few functional responses each minute (see Table 3), there were enough of these responses to compute mean peak force and mean response duration. In the punishment component during P, response force increased for H23, decreased for H31 and did not change for H34 (Row 2 of Figure 4). In the no-punishment component during P, there was a decrease in response force for H31, a slight decrease with overlap for H34, and no change for H23. Note that H23 was the only subject for whom functional responses were not followed by a click.

For each subject there was a consistent increase in response duration in the punishment component during P (triangles in Row 3 of Figure 4). In the no-punishment component during P, for H31 there was an increase in response duration, but for H23 and H34 there was no change from $\bar{P}$.

In the punishment component during P, for H34 there was a consistent increase in the proportion of subcriterion responses, and for H23 and H31 there were transient increases (bottom row of Figure 4). In the no-punishment component during P, there was no systematic change in subcriterion responding from $\bar{P}$.

GENERAL DISCUSSION

The goal of the present experiments was to determine the conditions under which punishment contrast and punishment induction occur. Contrast and induction occurred when rate of reinforcement and punisher intensity were held constant, with and without blackouts between components, with and without discriminative stimuli correlated with the punishment condition, and with both electric-shock and response-cost punishers. Furthermore, contrast, induction, or both occurred in each of the present experiments. Contrast occurred consistently only during the first punishment condition of Experiment 1, when there were discriminative stimuli correlated with punishment. Even when

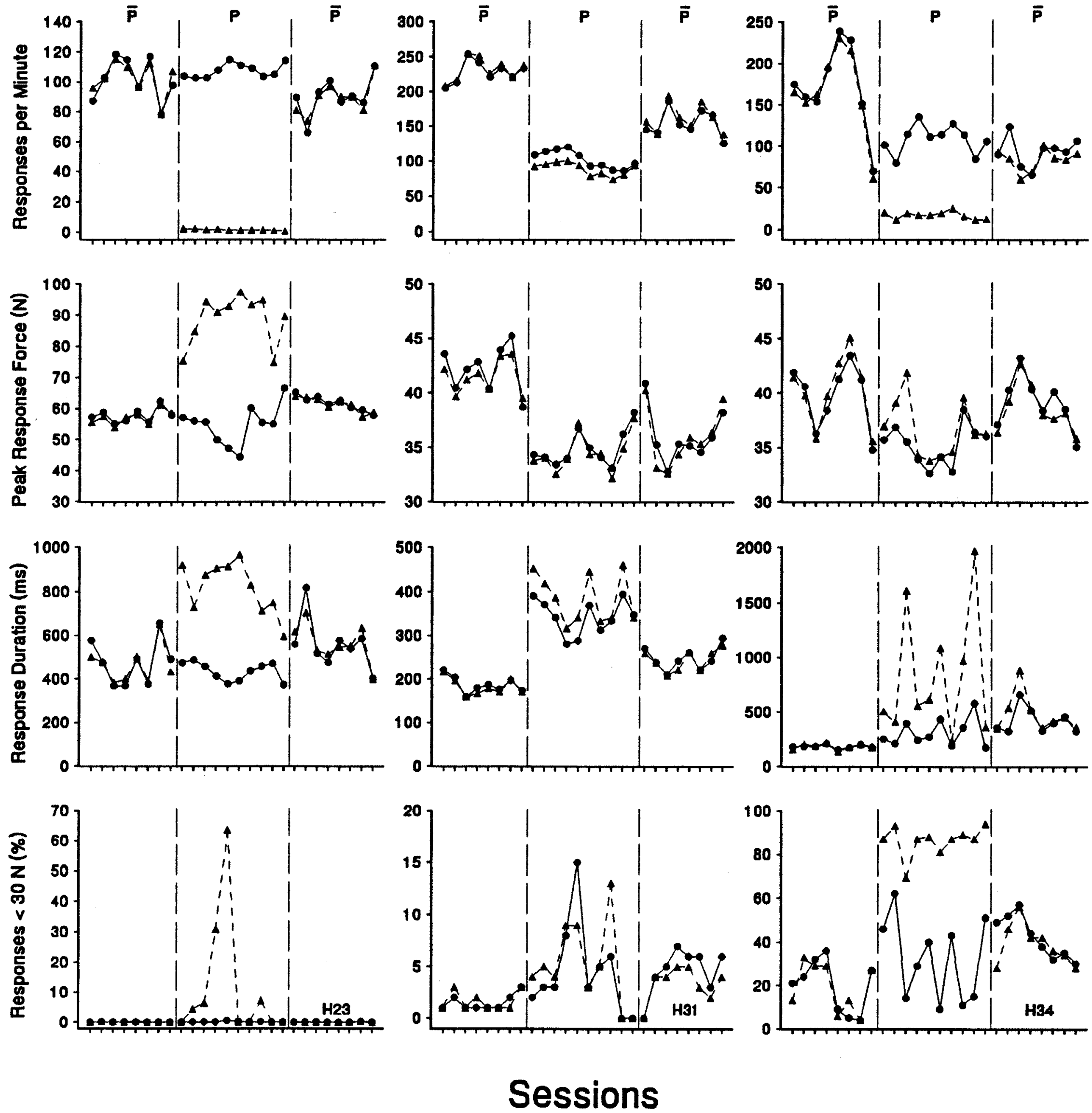

Fig. 4. Experiment 3: Rate, peak force, and duration of functional responses (i.e., peak force greater than 30 N), and the percentage of subcriterion responses (i.e., peak force 10 N to 29 N) in each component during the final eight sessions of conditions without punishment ($\overline{P}$) and the final 10 sessions of the condition with punishment (P). Circles show the component in which responding was never punished; triangles show the component in which every response was punished during P. Circle components were correlated with a green rectangle; triangle components were correlated with a red rectangle. There was a 15-s blackout between components.

contrast occurred, however, the failure of response rates in the no-punishment component to return to prepunishment levels when punishment was discontinued casts doubt on the robustness of the effect. During subsequent punishment conditions of Experiment 1 and in the other two experiments, the most common finding was induction, which occurred regardless of the type of punisher and whether there were discriminative stimuli correlated with punishment.

The present results also suggest four additional variables that might determine whether punishment produces contrast or induction: prior history, individual differences, manner of punisher introduction, and stimulus factors. Each of these variables is discussed below.

Rachlin (1966, Experiment 2) reinforced responding in both components of a multiple schedule, then presented mild electric shock after every response in one component. The sequence of no shock in both components, then shock in one component, was arranged three times. Although there was no change in response rate during no-punishment components, suppression during punishment components was greater during the second and third sequences than during the first sequence, which suggests a sensitization effect. Similar sensitization was observed in the present Experiment 1. A shock of lower intensity generally was required in subsequent punishment conditions to produce the same amount of suppression (a 50% reduction in responding) that was observed during the first punishment condition. Taken together, the results of Rachlin's experiments and the present experiments suggest that the appearance of induction, rather than contrast, during subsequent exposures to punishment may be related in part to the sensitization of responding in the punishment component.

Individual differences among subjects in reactivity to shock punishers is well known among researchers in the area of punishment. This observation was confirmed once again in the present Experiments 1 and 2 by the range of shock intensities that were required to yield a 50% reduction in response rates in the punishment component. Similarly in Experiment 3, different magnitudes of point loss were required to achieve the suppression criterion. In previous investigations of the effects of punishment on unpunished behavior, all subjects received the same shock intensity within a condition, which might have increased the variability of those results. Individual differences in sensitivity to punishers provides only a partial explanation of the variability of previous results, however, because the present results were variable despite the use of a functional definition of punishment that accommodates subjects' sensitivity.

Azrin (1960) found that the sudden introduction of intense electric shock following each response on a VI schedule of positive reinforcement massively disrupted all behavior in the experimental chamber. Indeed, responding on the operandum recurred only after punishment was removed and the response was reshaped manually. In the present Experiment 1, shock intensity was increased slowly from an imperceptible level to one that reduced responding by 50%. This led to contrast rather than induction during the first punishment condition. The gradual introduction of shock punishment may preclude the massive induction effects observed by Azrin (1960); it will not eliminate induction, however, because induction was the most common occurrence during subsequent punishment conditions of the present Experiment 1.

It is surprising that the similarity of stimuli correlated with punishment and no-punishment components in the present Experiments 1 and 2 made no difference in the effects of punishment on unpunished responding. Previous studies have shown that pigeons can discriminate between the yellow, blue, white, and green key colors used in the present experiments (e.g., Honig & Slivka, 1964). Hence, it is unlikely that the failure of programmed stimuli to control responding was because those stimuli were physically indiscriminable. A more likely possibility is that key color was masked by the presence or absence of shock. During the first condition without punishment, responding was reinforced on identical schedules in the presence of all key colors. Hence, during that condition, key color was functionally irrelevant. During the condition with punishment, one key color was correlated with the punishment component, but so was electric shock, which probably was a more salient stimulus (Azrin & Holz, 1966; Holz & Azrin, 1961). Key color was not required to determine the prevailing experimental condition because electric shock immediately followed every peck in the punishment component. Given that key color was irrelevant for several sessions in the first condition without punishment and that it was not required to discriminate between components in the condition with punishment, it is likely that key color never was a functional stimulus. It is not clear why the presence of the punisher masked programmed stimuli in the present experiments but not in those of Honig and Slivka (1964). What is clear, however, is that the discriminative properties of punishment cannot be ignored when considering the effects of punishment on unpunished responding.

In the present Experiment 3, punishment affected both the rate and the topography of the punished response. The most consistent change in response topography was the increase in response duration. Because the punisher followed lever release, longer responses postponed the punisher, and therefore response duration may have increased because of negative reinforcement. Alternatively, punishment may have slowed responding (e.g., Barlow, 1933; Donahue & Ratliff, 1976; Tindall & Ratliff, 1974). If increased response duration is produced by avoidance of the punisher, then response speed should decrease prior to punisher delivery. One way to test that proposition is to measure rats' running speed in several sections of a runway, then pass electric current through one section of the runway floor. Reduced running speed only in sections immediately before the shock would support the avoidance explanation; reduced running speed throughout the runway would support the notion that punishment produces a general slowing of all aspects of responding. A similar test could be performed with a free-operant procedure such as that used in the present Experiment 3. Components of a response could be timed (e.g., from 10 N to 30 N and from 30 N to 3 N), and the punisher presented at either 30 N or 3 N.

Punishment also increased the proportion of subcriterion responses (i.e., those that did not meet the force threshold for reinforcement and punishment). Subcriterion responses were never reinforced, but neither were they punished. Perhaps they increased in frequency because they avoided or postponed the punisher (as was found by Dunham, Mariner, & Adams, 1969, and Hearst & Sidman, 1961). In future studies, more punishment conditions should be used to determine whether increased subcriterion responding is transient or permanent.

Given that punishment simultaneously decreases response rate and increases response duration (see Figure 4), it is possible that induction reflects a change in response topography rather than a reduction in responding. That is, the increases in response duration may completely compensate for the decreases in response rate such that the organism spends as much total time responding in the punishment condition as it did in the condition without punishment. One way to test that proposition would be to add the duration of every response to obtain the total time spent responding and then compare that total time with the duration of a session. Thus, the proportion of a session spent responding could provide a measure of responding that accommodates topographical response changes produced by punishment.

Response topography also might be important as an independent variable when considering the effects of punishment on unpunished responses. In each of the present experiments, punished and unpunished responses had an identical form and location. Perhaps topographical similarity produced generalized suppression in most punishment conditions, which is why induction was the most common occurrence. One way to test that proposition would be to arrange a multiple schedule in which humans press a lever vertically with the left hand in one component and pull a plunger horizontally with the right hand in the other component. When responding is stable, every lever press would be followed by point loss. Response topography may be both an important independent and dependent variable when punishment effects are considered.

The main theoretical accounts of contrast are based on changes in relative reinforcement rate (Herrnstein, 1970; Reynolds, 1961b), a "worsening of conditions" (e.g., Mackintosh, 1974; Premack, 1969), and emotional mechanisms (Amsel, 1958; Bloomfield, 1969; Terrace, 1966). None of these accounts can adequately explain the present findings of induction under conditions in which contrast might have been expected.

Although the present results have not shown which variables determine whether punishment contrast or induction occurs, they have identified several variables that do not seem to be relevant, uncovered new variables that need to be assessed, and highlighted some important methodological considerations that should be addressed in such assessments. Although the present results do not support any existing theory of schedule interactions involving punishment, they highlight the deficiencies of each, and provide new results that need to be explained.

REFERENCES

Amsel, A. (1958). The role of frustrative nonreward in noncontinuous reward situations. *Psychological Bulletin, 55,* 102–119.

Azrin, N. H. (1959). A technique for delivering shock to pigeons. *Journal of the Experimental Analysis of Behavior, 2,* 161–163.

Azrin, N. H. (1960). Effects of punishment intensity during variable-interval reinforcement. *Journal of the Experimental Analysis of Behavior, 3,* 123–142.

Azrin, N. H., & Holz, W. C. (1966). Punishment. In W. K. Honig (Ed.), *Operant behavior: Areas of research and application* (pp. 380–447). Englewood Cliffs, NJ: Prentice Hall.

Barlow, M. C. (1933). The influence of electric shock in mirror tracing. *American Journal of Psychology, 45,* 478–487.

Baron, A. (1991). Avoidance and punishment. In I. H. Iversen & K. A. Lattal (Eds.), *Techniques in the behavioral and neural sciences: Vol. 6. Experimental analysis of behavior: Part 1* (pp. 173–217). Amsterdam: Elsevier.

Bloomfield, T. M. (1969). Behavioral contrast and the peak shift. In R. M. Gilbert & N. S. Sutherland (Eds.), *Animal discrimination learning* (pp. 215–241). London: Academic Press.

Brethower, D. M., & Reynolds, G. S. (1962). A facilitative effect of punishment on unpunished behavior. *Journal of the Experimental Analysis of Behavior, 5,* 191–199.

Crosbie, J. (1993). The effects of response cost and response restriction on a multiple-response repertoire with humans. *Journal of the Experimental Analysis of Behavior, 59,* 173–192.

Crosbie, J. (in press). Negative reinforcement and punishment. In K. A. Lattal & M. Perone (Eds.), *Handbook of research methods in human operant behavior.* Hillsdale, NJ: Erlbaum.

Donahue, B., & Ratliff, R. G. (1976). The effects of reward, punishment, and knowledge of results on children's discrimination learning. *Journal of Genetic Psychology, 129,* 97–103.

Dunham, P. J., Mariner, A., & Adams, H. (1969). Enhancement of off-key pecking by on-key punishment. *Journal of the Experimental Analysis of Behavior, 12,* 789–797.

Fleshler, M., & Hoffman, H. S. (1962). A progression for generating variable-interval schedules. *Journal of the Experimental Analysis of Behavior, 5,* 529–530.

Fowler, S. C. (1987). Force and duration of operant responses as dependent variables in behavioral pharmacology. In T. Thompson, P. B. Dews, & J. E. Barrett (Eds.), *Neurobehavioral pharmacology* (Vol. 6, pp. 83–127). Hillsdale, NJ: Erlbaum.

Hearst, E., & Sidman, M. (1961). Some behavioral effects of a concurrently positive and negative stimulus. *Journal of the Experimental Analysis of Behavior, 4,* 251–256.

Herrnstein, R. J. (1970). On the law of effect. *Journal of the Experimental Analysis of Behavior, 13,* 243–266.

Hoffman, H. S., & Fleshler, M. (1965). Stimulus aspects of aversive controls: The effects of response contingent shock. *Journal of the Experimental Analysis of Behavior, 8,* 89–96.

Holz, W. C., & Azrin, N. H. (1961). Discriminative properties of punishment. *Journal of the Experimental Analysis of Behavior, 4,* 225–232.

Honig, W. K., & Slivka, R. M. (1964). Stimulus generalization of the effects of punishment. *Journal of the Experimental Analysis of Behavior, 7,* 21–25.

Killeen, P. R. (1978). Stability criteria. *Journal of the Experimental Analysis of Behavior, 29,* 17–25.

Lattal, K. A., & Griffin, M. A. (1972). Punishment contrast during free-operant avoidance. *Journal of the Experimental Analysis of Behavior, 18,* 509–516.

Mackintosh, N. J. (1974). *The psychology of animal learning.* London: Academic Press.

Matthews, B. A., Shimoff, E., Catania, A. C., & Sagvolden, T. (1977). Uninstructed human responding: Sensitivity to ratio and interval contingencies. *Journal of the Experimental Analysis of Behavior, 27,* 453–467.

Morse, W. H., & Skinner, B. F. (1957). A second type of superstition in the pigeon. *American Journal of Psychology, 70,* 308–311.

Notterman, J. M., & Mintz, D. E. (1965). *Dynamics of response.* New York: Wiley.

Premack, D. (1969). On some boundary conditions of contrast. In J. T. Tapp (Ed.), *Reinforcement and behavior* (pp. 120–145). New York: Academic Press.

Rachlin, H. (1966). Recovery of responses during mild punishment. *Journal of the Experimental Analysis of Behavior, 9,* 251–263.

Reynolds, G. S. (1961a). An analysis of interactions in a multiple schedule. *Journal of the Experimental Analysis of Behavior, 4,* 107–117.

Reynolds, G. S. (1961b). Behavioral contrast. *Journal of the Experimental Analysis of Behavior, 4,* 57–71.

Terrace, H. S. (1966). Behavioral contrast and the peak shift: Effects of extended discrimination training. *Journal of the Experimental Analysis of Behavior, 9,* 613–617.

Tindall, R. C., & Ratliff, R. G. (1974). Interaction of reinforcement conditions and developmental level in a two-choice discrimination task with children. *Journal of Experimental Child Psychology, 18,* 183–189.

Tullis, C., & Walters, G. (1968). Punished and unpunished responding in multiple variable-interval schedules. *Journal of the Experimental Analysis of Behavior, 11,* 147–152.

Received May 9, 1994
Final acceptance May 29, 1997