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MOLECULAR CONTINGENCIES IN SCHEDULES OF INTERMITTENT PUNISHMENT

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In two experiments, key pecking of pigeons was maintained by a variable-interval 180-s schedule of food presentation. Conjointly, a second schedule delivered response-dependent electric shock. In the first experiment, shocks were presented according to either a variable-interval or a nondifferential interval-percentile schedule. The variable-interval shock schedule differentially delivered shocks following long interresponse times. Although the nondifferential shock schedules delivered shocks less differentially with respect to interresponse times, the two shock schedules equally reduced the relative frequency of long interresponse times. The second experiment differentially shocked long or short interresponse times in different conditions, with resulting decreases in the relative frequency of the targeted interresponse times. These experiments highlight the importance of selecting the appropriate level of analysis for the interaction of behavior and environment. Orderly relations present at one level of analysis (e.g., interresponse times) may not be revealed at other levels of analysis (e.g., overall response rate).

Key words: punishment, interresponse times, response-dependent shocks, variable-interval schedules, percentile schedules, key peck, pigeons

Conceptualizing punishment as a primary process analogous to reinforcement allowed Azrin and Holz (1966) to categorize and summarize punishment research using the same parameters and controlling variables as those that describe reinforcement research. For example, they found that punishment effects depend on variables related to the administration of the punishing stimuli (e.g., immediacy, frequency, intensity, and the schedule of punishment). The focus on schedules and schedule parameters has guided punishment research just as a similar focus has guided reinforcement research.

Consistent, orderly relations generally are obtained between schedule parameters and punishment. Responding is suppressed as a direct function of intensity and frequency of the punisher under fixed-ratio (FR; e.g., Azrin, Holz, & Hake, 1963; Powell, 1971; Thomas, 1968; Zimmerman & Baydan, 1963), variable-ratio (VR; e.g., Bradshaw, Szabadi, & Bevan, 1979; Dardano, 1972), and fixed-interval (FI; e.g., Appel, 1968; Azrin, 1956) schedules of punishment.

With variable-interval (VI) schedules of punishment, however, intensity and frequency manipulations have not consistently produced the orderly effects seen with other schedules of punishment. This inconsistency is evident in two ways. First, within a limited range of punishing stimulus parameters (e.g., intensity; Filby & Appel, 1966), putative VI punishment schedules increase response rates relative to unpunished baseline rates (Arbuckle & Lattal, 1987; Filby & Appel, 1966). At other parameters, response suppression may be obtained. Thus, although VI punishment can be obtained, it seems constrained within a limited range of parameters. Second, with VI punishment there is sometimes a lack of intermediate degrees of response suppression (but cf. Lattal, 1969, Experiment 1). For example, Filby and Appel (1966) reported response facilitation at lower punishment intensities and response suppression with more intense punishment. The suppression, however, tended to be all or none, with response rates near or above base-

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line rates at one intensity but plummeting to near zero at the next highest intensity. Similar effects were reported by Azrin (1956) and Arbuckle and Lattal (1987).

Both of these apparent inconsistencies between VI and other schedules of punishment may be clarified by examining the relation between responses and stimulus presentations in VI schedules. For example, Galbicka and Branch (1981) differentially punished long interresponse times (IRTs). As the frequency of the punished long IRTs decreased, overall response rates increased over no-shock baseline levels. Galbicka and Branch suggested that because VI schedules reinforce relatively long IRTs differentially (e.g., Morse, 1966), VI punishment schedules may punish long IRTs differentially, thereby increasing overall response rates.

With respect to intermediate suppression, VI schedules maintain a constant overall frequency of event presentations over a range of response rates provided responding exceeds some minimal level. Low response rates increase the probability that the next response will be punished, because the longer the subject pauses between responses the more probable it is that the current interpunishment interval will lapse before the next response. In fact, response rates could be low enough so that each response is punished. This may suppress response rates further so that once response rates are reduced, the suppression may accelerate quickly and produce the almost complete response elimination that has been observed. If, on the other hand, response rates initially increase when punished, for whatever reason, then shock probability per response will decrease. This could produce the attenuated suppression and even facilitation of responding.

The effects of VI punishment on overall response rates may be understood further by matching the level of analysis to the level at which the contingencies operate. Because VI schedules differentiate behavior at multiple levels (both IRTs and single key pecks), a molecular analysis is appropriate to examine the IRT contingencies inherent in VI punishment. Experiment 1 provides a molecular analysis of the relation between responses or response sequences and electric shock presentations that occur in VI schedules of shock delivery. Experiment 2 extends this analysis to schedules that differentially delivered shocks to long or short IRTs directly.

EXPERIMENT 1

This experiment examined the relation between responses and shocks produced by a VI shock schedule and compared the characteristics of this schedule to a VI-like shock schedule (a nondifferential interval-percentile schedule) that delivered shocks independently of the duration of the current IRT (cf. Kuch & Platt, 1976). This nondifferential schedule provided a comparison in which differential punishment of long IRTs was reduced and therefore allowed a molecular analysis of response sequences that immediately precede and produce punishers during VI punishment. The effects of the nondifferential schedule were studied in their own right by providing VI-like temporal scheduling of shock deliveries without the differential punishment of long IRTs present in the VI schedules.

METHOD

Subjects

Three naive White Carneau pigeons were maintained at approximately 80% of their free-feeding weights. Water and Palmetto health grit were available continuously in their home cages.

Apparatus

The experiment was conducted in a standard experimental chamber for pigeons with internal dimensions of 30.5 cm long by 30.5 cm wide by 38 cm high. The response key (2 cm diameter) was located on the work panel 7.6 cm from the right wall and 24.4 cm from the floor of the chamber. A force of at least 0.13 N was required to operate the key. The key was transilluminated blue by a 28-V DC bulb at all times during experimental sessions except during the delivery of reinforcers. General illumination of the chamber was provided by a white 7-W 120-V AC bulb that was also constantly illuminated except during food presentations. Reinforcers consisted of 4-s access to Purina® mixed pigeon grain in a standard food magazine accessible through an opening on the center of the work panel, 8.3 cm from the floor. The opening was illuminated by a white 6-W 125-V AC bulb when the magazine was operated. Punishing stimuli consisted of 0.07-s 60-Hz AC shocks delivered through a 10,000-ohm series resistor to implanted electrodes (Azrin, 1959). Every 10 V was equivalent to approximately 1 mA. Other aspects of the shock delivery were as described by Azrin and Holz (1966). Experimental conditions and data collection were controlled from an adjacent room by a PDP 8/a® minicomputer using SuperSKED® software.

Procedure

Key pecking of each bird was hand shaped, after which each bird received preliminary training on a series of VI food-presentation schedules of increasing values over several sessions until the mean interfood interval reached 180 s. The interfood intervals of the VI 180-s schedule were arranged by a constant-probability distribution of 12 intervals (Fleshler & Hoffman, 1962). When responding was stable, shocks were presented conjointly according to a VI 30-s schedule such that key pecks independently produced both reinforcers and shocks on each of their respective schedules. The conjoint schedule occasionally allowed food and shock to occur simultaneously, but the number of such pairings was inconsequential. The VI 30-s schedule consisted of 50 intervals derived from the Fleshler and Hoffman constant-probability distribution. Shock intensity initially was 10 V and was changed in 10-V increments in subsequent conditions. Intensity was increased for each bird until extreme degrees of response suppression (overall response rates near zero, with intermittent periods of no responding lasting several minutes) or consistent increases in response rates (as compared to baseline) were observed. After response rates stabilized at the maximum shock intensity during the VI 30-s shock condition, the VI 180-s food-only condition (no-shock baseline) was reinstated.

Subsequently, the same sequence of shock intensities delivered previously under the conjoint VI schedule was effected, except that the shocks were delivered conjointly according to a nondifferential shock schedule (Platt, 1973). Under this nondifferential schedule, the probability of shock was revised with every response. The probability of shock for each response was calculated based on a recent sample of the subject's behavior so that approximately two shocks per minute were delivered. This sample was the most recent minimum number of IRTs whose cumulative duration was at least 60 s. Kuch and Platt (1976) asserted that a sampling period of two times the nominal interstimulus interval (2 × 30 s in this case) provides a reasonable estimate of the current IRT distribution that is sensitive to changes in response rate without being affected by short-term sequential dependencies between responses. The probability of shock for a given response was set equal to $p = t/Tm$, where p equals the probability of shock, t equals the cumulative time in the sampling list, T equals the nominal intershock interval (30 s), and m equals the number of IRTs in the sampling list (Platt, 1973). The current IRT was added to the sampling list only after the shock probability was calculated for that IRT; hence, shock probability was independent of its duration. Postreinforcement pauses and the latency to the first response of the session were not included in these calculations. These pauses were not excluded from the operation of the VI shock schedule. This difference did not affect shock rate between the two classes of schedules, as shown by the shock-rate data in Table 1.

After the sequence of shock intensities with the nondifferential schedules, the VI 180-s food-only condition was reintroduced. Next, in the final third of the study, the VI 30-s sequence of shock-intensity conditions was replicated. Two subjects were also exposed to the nondifferential shock schedule at one shock intensity during this part of the study. The sequence of conditions and number of sessions for each subject are shown in Table 1.

Each condition was in effect for a minimum of 10 sessions and ended when the response rates were stable. Stability was defined as no monotonic trend in the mean response rates of the most recent three blocks of three sessions. The only exception to meeting this criterion was in the first nondifferential 40-V condition for P3391. Due to a computer breakdown, the experiment was suspended for several weeks, and response rates for P3391 did not recover to prebreakdown levels (although they did stabilize). In this one instance, data analyses were based on the last nine (nonstable) sessions before the breakdown. In all other cases, data analyses were based on the last nine sessions of the condition. Sessions were conducted 7 days per week and lasted approximately 60 min.

RESULTS

Table 1 presents means and ranges of shocks per minute for each subject. Both the VI and the nondifferential shock schedules maintained fairly constant shock rates around the nominal

Table 1

Sequence of experimental conditions, number of sessions, mean responses per minute, mean reinforcers per minute, mean shocks per minute, and mean and median shocked IRTs for each subject in the first experiment (ranges are in parentheses). Each of the three rate measures and the shocked IRT values were computed over the last nine sessions of the specified condition. All baselines were without shock. Shock conditions are labeled either VI (indicating the VI shock schedule) or ND (indicating the nondifferential schedule) and the corresponding shock voltage.

						Shocked IRTs	
Subject	Condition	Sessions	Resp/min	Reinf/min	Shocks/min	Mean	Median
P3391	Baseline	60	50	0.33	—	—	—
			(38–65)	(0.26–0.36)	—	—	
	VI 10 V	20	45	0.32	1.92	2.61	1.97
			(37–53)	(0.26–0.36)	(1.78–2.02)	(0.06–24.49)	
	VI 20 V	10	47	0.32	1.93	2.55	1.96
			(37–57)	(0.28–0.34)	(1.81–2.05)	(0.04–23.04)	
	VI 30 V	13	56	0.32	1.94	2.06	1.60
			(49–63)	(0.26–0.36)	(1.85–2.02)	(0.05–27.74)	
	VI 40 V	16	80	0.31	1.93	1.25	0.93
			(77–84)	(0.28–0.36)	(1.86–2.04)	(0.05–9.72)	
	Baseline	10	70	0.30	—	—	—
			(62–79)	(0.28–0.33)	—	—	
	ND 10 V	10	74	0.33	2.06	0.89	0.68
			(52–85)	(0.26–0.36)	(1.86–2.35)	(0.03–8.37)	
	ND 20 V	12	100	0.33	1.95	0.61	0.56
			(92–105)	(0.28–0.36)	(1.82–2.14)	(0.03–8.00)	
	ND 30 V	10	97	0.32	1.95	0.63	0.56
			(86–106)	(0.29–0.36)	(1.80–2.34)	(0.03–21.39)	
	ND 40 V	12	106	0.31	1.99	0.59	0.54
			(98–114)	(0.26–0.34)	(1.69–2.18)	(0.03–6.02)	
	Baseline	11	84	0.32	—	—	—
			(78–90)	(0.29–0.34)	—	—	
	VI 10 V	11	92	0.31	1.97	1.08	0.92
			(76–98)	(0.28–0.36)	(1.86–2.05)	(0.06–11.91)	
	VI 20 V	11	92	0.32	1.96	1.10	0.91
			(87–99)	(0.28–0.36)	(1.86–2.02)	(0.04–11.56)	
	VI 30 V	16	93	0.33	1.96	1.20	0.91
			(82–100)	(0.29–0.34)	(1.91–2.03)	(0.05–14.80)	
	VI 40 V	12	91	0.32	1.94	1.23	1.00
			(84–100)	(0.28–0.36)	(1.81–2.06)	(0.04–15.49)	
	ND 40 V	11	96	0.34	2.08	0.63	0.55
			(86–107)	(0.33–0.36)	(1.86–2.28)	(0.03–6.49)	
	VI 40 V	14	111	0.30	1.97	1.16	0.87
			(97–115)	(0.26–0.34)	(1.88–2.04)	(0.03–68.42)	
P3752	Baseline	11	43	0.32	—	—	—
			(39–47)	(0.26–0.36)	—	—	
	VI 10 V	11	43	0.31	1.91	1.75	1.64
			(41–46)	(0.28–0.34)	(1.80–2.01)	(0.07–11.22)	
	VI 20 V	11	47	0.31	1.92	1.67	1.59
			(43–50)	(0.28–0.36)	(1.80–2.01)	(0.06–13.26)	
	VI 30 V	39	57	0.31	1.95	1.44	1.31
			(49–65)	(0.29–0.34)	(1.86–2.07)	(0.05–39.06)	
	VI 40 V	33	60	0.30	1.78	1.64	1.10
			(53–64)	(0.25–0.36)	(1.41–1.91)	(0.07–67.63)	
	Baseline	16	63	0.32	—	—	—
			(56–67)	(0.28–0.36)	—	—	
	ND 10 V	10	65	0.32	2.05	0.91	0.86
			(62–70)	(0.28–0.36)	(1.84–2.28)	(0.03–5.92)	
	ND 20 V	13	74	0.32	2.01	0.80	0.74
			(69–80)	(0.29–0.34)	(1.77–2.23)	(0.03–4.45)	
	ND 30 V	10	72	0.32	2.03	0.81	0.77
			(70–77)	(0.26–0.34)	(1.67–2.16)	(0.03–4.68)	

Table 1

(Continued)

Subject	Condition	Sessions	Resp/min	Reinf/min	Shocks/min	Shocked IRTs	
						Mean	Median
	ND 40 V	23	72	0.33	1.98	0.99	0.66
			(63–72)	(0.29–0.36)	(1.75–2.18)	(0.03–38.99)	
	Baseline	10	64	0.31	—	—	—
			(60–74)	(0.26–0.34)	—	—	
	VI 10 V	13	66	0.31	1.96	1.42	1.27
			(62–72)	(0.28–0.34)	(1.91–2.00)	(0.05–26.51)	
	VI 20 V	19	70	0.32	1.96	1.25	1.24
			(67–75)	(0.28–0.36)	(1.88–2.09)	(0.08–11.94)	
	VI 30 V	13	69	0.33	1.97	1.26	1.19
			(64–73)	(0.29–0.34)	(1.91–2.04)	(0.03–49.94)	
	VI 40 V	12	74	0.33	1.93	1.33	1.14
			(70–77)	(0.29–0.36)	(1.88–2.04)	(0.03–35.17)	
	ND 40 V	10	69	0.32	2.04	0.92	0.78
			(65–73)	(0.29–0.34)	(1.56–2.22)	(0.03–8.96)	
P3781	Baseline	12	45	0.32	—	—	—
			(43–48)	(0.29–0.34)	—	—	
	VI 10 V	11	38	0.31	1.92	2.22	2.10
			(34–43)	(0.28–0.36)	(1.85–1.98)	(0.07–11.29)	
	VI 20 V	11	40	0.32	1.95	2.05	1.56
			(33–45)	(0.28–0.34)	(1.86–2.01)	(0.07–12.10)	
	VI 30 V	10	39	0.33	1.95	2.00	1.74
			(36–43)	(0.31–0.36)	(1.90–1.99)	(0.08–12.44)	
	VI 40 V	10	40	0.31	1.93	2.04	1.95
			(36–45)	(0.28–0.36)	(1.86–2.02)	(0.06–8.02)	
	VI 50 V	25	62	0.31	1.94	1.54	1.40
			(56–66)	(0.28–0.36)	(1.86–2.04)	(0.05–16.45)	
	Baseline	15	64	0.32	—	—	—
			(58–68)	(0.26–0.36)	—	—	
	ND 10 V	10	66	0.31	1.90	0.94	0.82
			(62–70)	(0.28–0.34)	(1.46–2.09)	(0.03–19.34)	
	ND 20 V	11	71	0.32	2.03	0.82	0.72
			(65–78)	(0.28–0.36)	(1.72–2.25)	(0.03–4.89)	
	ND 30 V	22	88	0.32	2.06	0.68	0.64
			(81–97)	(0.26–0.36)	(1.91–2.32)	(0.03–6.68)	
	ND 40 V	21	88	0.33	1.94	0.68	0.63
			(84–94)	(0.29–0.36)	(1.67–2.07)	(0.03–10.39)	
	ND 50 V	17	102	0.32	2.01	0.58	0.58
			(93–108)	(0.26–0.36)	(1.75–2.25)	(0.03–6.67)	
	Baseline	14	102	0.32	—	—	—
			(98–107)	(0.31–0.34)	—	—	
	VI 10 V	13	85	0.33	1.97	1.34	0.90
			(72–95)	(0.29–0.36)	(1.91–2.04)	(0.03–14.09)	
	VI 20 V	15	94	0.31	2.00	1.10	0.84
			(83–99)	(0.28–0.34)	(1.94–2.04)	(0.03–7.83)	
	VI 30 V	21	85	0.32	1.97	1.13	0.82
			(76–90)	(0.26–0.36)	(1.88–2.09)	(0.05–9.10)	
	VI 40 V	10	83	0.34	1.96	1.25	0.91
			(78–89)	(0.28–0.36)	(1.83–2.07)	(0.06–11.34)	
	VI 50 V	14	75	0.32	1.94	1.42	1.14
			(69–80)	(0.29–0.36)	(1.86–1.99)	(0.04–10.77)	

value of 2.0 shocks per minute. The differences in shock rate maintained by the two shock schedules were trivial (average intershock intervals were 31 s for the VI schedules and 30 s for the nondifferential schedules across all subjects). The shock rates generated by the nondifferential schedules tended to be more variable than those generated by the VI sched-

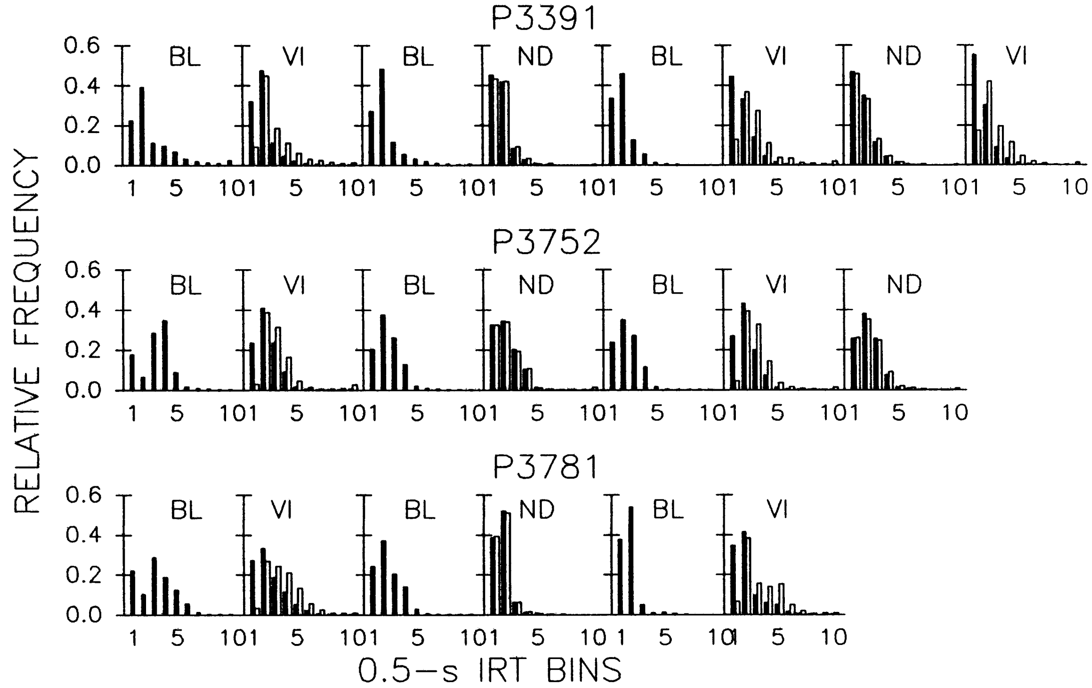

Fig. 1. Relative frequencies of overall (solid bars) and shocked (open bars) IRTs in successive 0.5-s IRT bins averaged over the last nine sessions of conditions for each subject in the first experiment. Bin 10 includes all IRTs ≥4.5 s. Condition labels indicate no-shock baselines (BL) or the VI (VI) or nondifferential (ND) shock schedule. Distributions labeled VI or ND are from the maximum-voltage conditions.

ules, especially in the upper ranges of the shock rates. This most likely was a result of the probabilistic nature of the nondifferential schedules.

Table 1 also presents the mean, median, and range of the shocked IRTs for each subject. The shocked IRTs consistently were longer for the VI versus the nondifferential schedules for all 3 subjects.

Distributions of overall and shocked IRTs for each subject averaged over the last nine sessions of each condition are depicted in Figure 1. Those for the VI and ND schedules are from conditions in which the highest shock intensity was studied. The relative frequencies were calculated based on all overall or shocked IRTs from the last nine sessions of each condition. Bin 10 includes IRTs ≥4.5 s. Overall IRT distributions during the initial no-shock baseline were unimodal with the mode in the second bin for P3391 and bimodal with modes in the first and fourth bins for P3752 and modes in the first and third bins for P3781. The overall IRT distributions became less dispersed and unimodal, with the mode in the first or second bin for all subjects during the first VI shock condition, and generally remained so for the subsequent conditions.

Shocked IRT distributions for nondifferential shock conditions closely matched the overall IRT distributions for each subject. Shocked IRT distributions for VI shock conditions were lower in the first bin and higher in the third through 10th bins compared to both the nondifferential shock and the overall IRT distributions.

An analysis of the overall and shocked IRT data (Figure 1) in terms of interresponse times per opportunity (IRTs/Op; Anger, 1956), which provides an estimate of the probability of an IRT given that an opportunity for that IRT has occurred (an IRT greater than or equal to that IRT), iterated the findings from the overall and shocked IRT distributions and are not included. In general, the overall IRT distributions tended to become more peaked during the initial shock conditions and remained so across the subsequent conditions, and the shocked IRT distributions tended to be lower in the first bin and higher in the

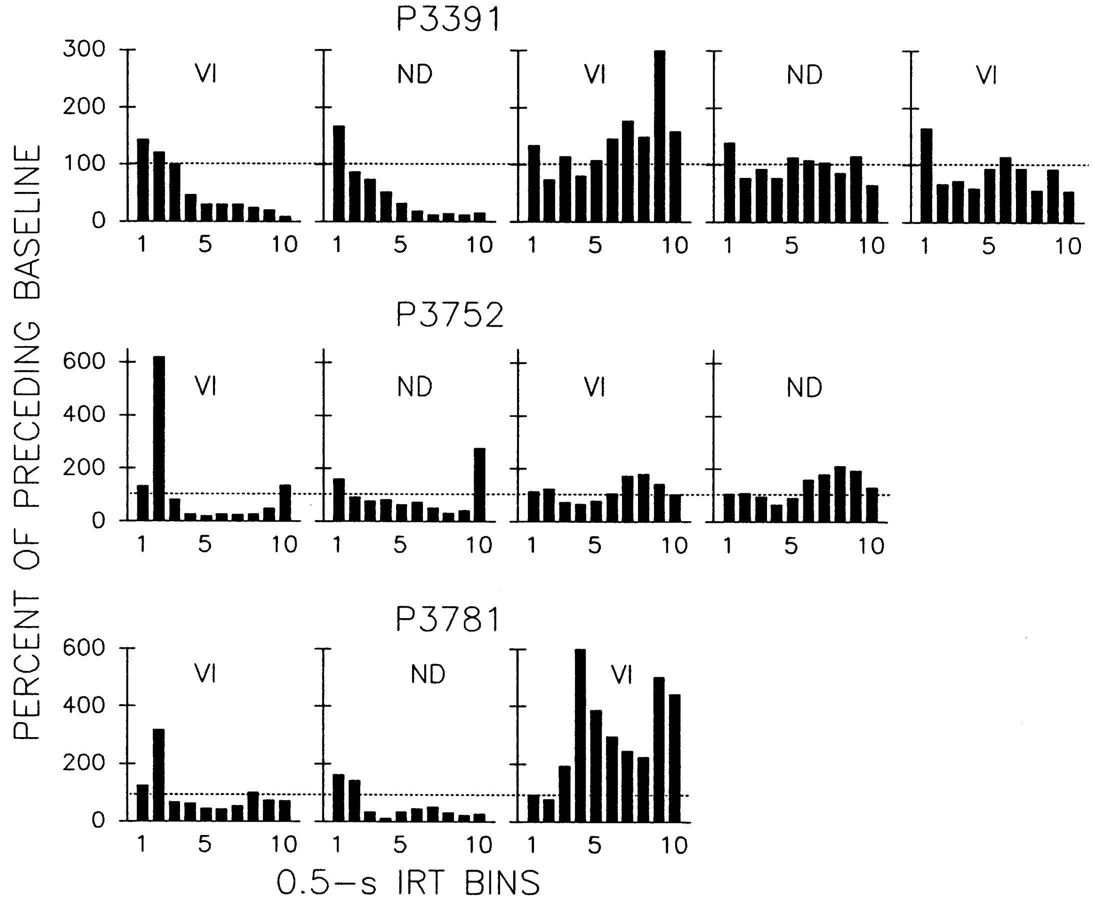

Fig. 2. Relative frequencies of overall IRTs plotted as a percentage of the preceding no-shock baseline in successive 0.5-s IRT bins averaged over the last nine sessions of each condition for each subject in the first experiment. Bin 10 includes all IRTs ≥4.5 s. Condition labels indicate the VI (VI) or nondifferential (ND) shock schedule. Dashed horizontal lines at 100% indicate no change from baseline.

longer bins during VI shock conditions compared to the nondifferential shock conditions.

Table 1 shows that overall response rates increased from no-shock baselines to the maximum-voltage shock conditions for both VI and nondifferential shock conditions. These response-rate increases occurred in all shock series for 2 of 3 subjects and in two of three shock series (initial VI and nondifferential) for the 3rd subject (P3781).

Overall IRT distributions are presented as a percentage of the preceding no-shock baseline for each subject in Figure 2. This depiction allows changes in IRT distributions from the previous no-shock baseline condition to be seen, even though the baseline patterns may have changed across successive exposures. Again, these data are from the maximum-voltage condition of each series. In general, the longer IRT bins decreased and the shorter IRT bins increased during the first VI and nondifferential shock conditions. There were no consistent changes across subjects in overall IRT distributions during the remaining shock conditions.

DISCUSSION

These data document that VI shock schedules differentially shocked long IRTs, as shown in the shocked IRT data (Figure 1). There was a corresponding decrease in the number of long IRTs (Figures 1 and 2) during the initial VI shock condition, suggesting that differential punishment of these IRTs did occur. This finding verifies Galbicka and Branch's (1981) speculation that VI punishment schedules differentially punish long IRTs and sheds light on the seemingly anomalous response-rate increases sometimes obtained with these schedules.

The nondifferential shock schedules generally shocked IRTs nondifferentially across most of the IRT bins (Figure 1). However, decreases in the longer bins of the overall IRT distributions (Figure 2) during the first nondifferential shock condition are similar to those of the first VI shock condition. This similarity in effect on overall IRT distributions (Figure 2) between the initial VI shock and nondifferential shock conditions weakens somewhat the suggestion that differential punishment of long IRTs was obtained during the initial VI shock condition. However, given the lack of any process during the nondifferential shock condition to oppose the differentiation obtained during the VI shock condition, it is less surprising that the VI and nondifferential shock conditions had similar effects. Once behavior was differentiated, making the contingency nondifferential may not have instated contingencies to reverse the behavior. This also may account for the effects on overall response rates. Consistent with previous research (Galbicka & Branch, 1981; Galbicka & Platt, 1984; Sizemore & Maxwell, 1985), overall response rates increased when long IRTs were shocked differentially. However, response rates tended not to return to preshock levels when subjects were reexposed to no-shock baseline conditions; rather, response rates tended to increase across the different shock schedules over successive conditions (e.g., response rates for P3781 increased from an average of 45 responses per minute in the first baseline to 102 responses per minute in the third baseline). This lack of recovery again may have reflected the lack of a contingency to oppose the differentiation that occurred previously.

The relatively high response rates also may have contributed to the absence of consistent differential punishment effects in the overall IRT distributions in the later shock conditions (cf. Figures 1 and 2). The increasing response rate caused by differential punishment of long IRTs lowers the probability of shock per response. This decrease in shock probability may lead to less response suppression (Azrin et al., 1963; cf. Galbicka & Platt, 1984). The progressively higher response rate caused by punishment of long IRTs, along with the concomitant decreases in shock probability per response, eventually reduces the effectiveness of the punishment and limits the IRT–punishment relation. These latter effects result in a ceiling in the IRT punishment effects and the response rate increases. Such a limit may have occurred in the present experiment during the second VI and following shock conditions. Because shock rate was relatively constant across the shock conditions and response rates increased (cf. Table 1), shock probability per response decreased. Consistent decreases in relative frequency of the long IRTs during these conditions did not occur in any subject.

EXPERIMENT 2

Experiment 1 examined molecular contingencies inherent in VI shock delivery schedules. The second experiment analyzed molecular contingencies in schedules of intermittent shock delivery in which either long or short IRTs were shocked directly. Galbicka and Branch (1981) and Sizemore and Maxwell (1985) allowed shock rate to vary as the frequency of the targeted IRTs varied. Thus the response-rate increases may have resulted from negative reinforcement of short IRTs rather than from the punishment of long IRTs. That is, response-rate increases decreased the shock rate and therefore may have been negatively reinforced (cf. Arbuckle & Lattal, 1987).

Galbicka and Platt (1984) addressed the possible negative reinforcement of short IRTs in long-IRT punishment procedures and attempted to correct it in their procedure. They used a VI-like linear IRT schedule that differentially punished long IRTs but maintained a roughly constant shock rate. Because of their use of a shock-avoidance schedule to maintain responding during some conditions, their control of shock rate was only approximate. In addition, the linear IRT procedure did not allow the differentiation of short IRTs.

The present experiment attempted to control punishment frequency stringently and to ensure that punishers were independent of the duration of contiguous IRTs. This procedure also addressed the differential punishment of short IRTs by comparing the short-IRT punishment procedure to a nondifferential procedure with the same shock rate. Short IRTs have not been punished differentially with electric shock (but cf. Ferster, 1958) in previous investigations, because the procedures did not allow the differentiation of short IRTs (the linear IRT procedure of Galbicka & Platt, 1984) or perhaps because the expected response-rate decreases would be in the same direction as would be expected by the molar effects of punishment.

METHOD

Subjects

Three naive White Carneau pigeons were maintained at approximately 80% of their free-feeding weights. Water and Palmetto health grit were available continuously in their home cages.

Apparatus

The apparatus was as described in Experiment 1, except that a force of at least 0.12 N was required to operate the key, and the opening of the food magazine was illuminated by a white 7-W 120-V AC bulb when the magazine was operated.

Procedure

Response shaping and preliminary training were as in Experiment 1. When responding was stable on the VI 180-s food schedule, shocks were introduced conjointly at 10 V, at approximately two per minute, according to a nondifferential interval-percentile schedule like the one used in Experiment 1. The shock voltages were increased in 10-V steps up to an experimentally determined maximum for each bird. This maximum voltage was determined either by a moderate degree of response-rate suppression or by continued high rates of responding at 50 V. For P3708, the voltage was increased to 50 V, and response rates were suppressed to low levels. The voltage was decreased to 40 V, and the response rates stabilized. The voltage then was increased in a 5-V increment up to the 45 V maximum for that subject during the initial nondifferential shock condition. Voltages remained at these maximum levels (45 V for P3708, 30 V for P741, and 50 V for P3802) throughout the remainder of the experiment.

Subjects then were exposed to alternating conditions of differential punishment of long and short IRTs in subsequent conditions of the experiment, with a nondifferential interval-percentile shock condition between the differential punishment conditions. The sequence of sessions at each condition is shown for each subject in Table 2.

The differential shock conditions in this experiment employed an interval-percentile schedule (Platt, 1973) similar to the nondifferential interval-percentile schedule used in Experiment 1. Shock delivery for each response was determined by a sample of the most recent IRTs totaling at least 60 s. In the case of the differential schedules, an IRT produced a shock if it was as extreme or more extreme (either long or short depending on the condition) than all but two of the IRTs in the current sampling list. Therefore, the second most extreme IRT in a sampling list set the current value of IRTs to be shocked. The current IRT was added to the list only after these comparisons were made. Because the sampling list was two times the nominal intershock interval (2 × 30 s), the criterion value determined by the second most extreme IRT resulted in an average of two shocks per minute, thus maintaining the constant targeted shock rate. Also, because the sampling list was constantly updated with the most current IRTs, this procedure remained responsive to changes in IRT distributions and set new criterion values that maintained the constant shock rate.

Each condition lasted for a minimum of 10 sessions and ended when the response rates were stable. The same stability criterion used in Experiment 1 was used here. All data analyses were based on the last nine sessions of each condition. Sessions were conducted 7 days per week and lasted approximately 60 min.

RESULTS

Table 2 presents means and ranges of shocks per minute for each subject. Both the nondifferential and the differential interval-percentile shock schedules maintained a fairly constant shock rate close to the nominal 2.0 shocks per minute.

Table 2 also presents means, medians, and ranges of the shocked IRTs for each of the shock conditions. These data show that the differential shock schedules shocked either long or short IRTs. The shocked IRTs for the nondifferential shock conditions were at values intermediate to those resulting from the long- and short-IRT shock conditions.

Figure 3 presents distributions of overall and shocked IRTs for each subject. Data were obtained, calculated, and organized as de-

Table 2

Sequence of experimental conditions, number of sessions, mean responses per minute, mean reinforcers per minute, mean shocks per minute, and mean and median shocked IRTs for each subject in the second experiment (ranges are in parentheses). Each of the three rate measures and the shocked IRT values were computed over the last nine sessions of the specified condition. Conditions are labeled either "no shock" for the initial no-shock baselines or "ND," "long," or "short," indicating that IRTs were shocked according to the nondifferential schedule or the differential punishment of long- or short-IRT shock schedule, respectively.

						Shocked IRTs	
Subject	Condition	Sessions	Resp/min	Reinf/min	Shocks/min	Mean	Median
P741	No shock	20	53	0.32	—	—	—
			(48–59)	(0.28–0.36)	—	—	
	ND 30 V	37	18	0.32	1.88	4.14	2.69
			(11–24)	(0.29–0.34)	(1.60–2.15)	(0.03–263.45)	
	Short 30 V	10	17	0.31	1.88	1.33	1.38
			(14–20)	(0.28–0.34)	(1.70–2.02)	(0.03–11.90)	
	ND 30 V	29	18	0.31	1.91	4.12	2.97
			(13–25)	(0.28–0.34)	(1.64–2.07)	(0.03–40.56)	
	Long 30 V	14	25	0.31	1.69	5.21	4.71
			(21–30)	(0.28–0.36)	(1.43–1.93)	(2.29–41.62)	
	ND 30 V	10	15	0.32	2.07	4.72	3.53
			(9–19)	(0.26–0.36)	(1.90–2.20)	(0.03–76.40)	
	Short 30 V	12	15	0.30	1.91	1.90	2.03
			(11–22)	(0.26–0.36)	(1.75–2.05)	(0.03–48.89)	
	ND 30 V	10	17	0.30	1.97	3.74	3.29
			(13–21)	(0.28–0.33)	(1.80–2.15)	(0.03–28.09)	
P3708	No shock	49	76	0.32	—	—	—
			(70–82)	(0.26–0.36)	—	—	
	ND 45 V	54	61	0.31	1.93	1.40	0.55
			(44–78)	(0.26–0.36)	(1.59–2.07)	(0.03–91.89)	
	Long 45 V	12	60	0.32	1.84	3.04	2.32
			(55–62)	(0.28–0.36)	(1.62–1.93)	(1.20–58.44)	
	ND 45 V	10	88	0.31	1.95	0.75	0.61
			(85–91)	(0.29–0.34)	(1.81–2.21)	(0.03–34.72)	
	Short 45 V	18	52	0.32	2.12	0.34	0.05
			(45–63)	(0.29–0.34)	(1.93–2.29)	(0.03–36.56)	
	ND 45 V	10	92	0.32	2.05	1.10	0.55
			(87–96)	(0.29–0.36)	(1.65–2.28)	(0.03–98.65)	
	Long 45 V	12	70	0.32	1.81	3.36	2.17
			(65–77)	(0.28–0.36)	(1.75–1.93)	(0.05–159.85)	
P3802	No shock	20	27	0.30	—	—	—
			(21–31)	(0.26–0.34)	—	—	
	ND 50 V	21	40	0.30	1.96	2.01	1.38
			(31–47)	(0.28–0.36)	(1.67–2.24)	(0.03–119.55)	
	Long 50 V	29	41	0.31	1.81	4.10	3.20
			(39–45)	(0.26–0.36)	(1.67–1.94)	(1.50–54.39)	
	ND 50 V	17	48	0.31	1.97	1.44	1.07
			(40–55)	(0.26–0.34)	(1.78–2.16)	(0.03–60.07)	
	Short 50 V	46	50	0.32	2.21	0.09	0.04
			(44–53)	(0.29–0.36)	(1.96–2.39)	(0.03–6.12)	
	ND 50 V	11	62	0.33	2.00	1.06	0.70
			(58–65)	(0.29–0.36)	(1.78–2.14)	(0.03–20.86)	
	Long 50 V	21	57	0.32	1.82	3.14	2.89
			(51–63)	(0.29–0.36)	(1.64–2.02)	(1.68–19.17)	
	ND 50 V	16	64	0.31	1.92	1.05	0.73
			(61–67)	(0.28–0.36)	(1.68–2.20)	(0.03–19.84)	

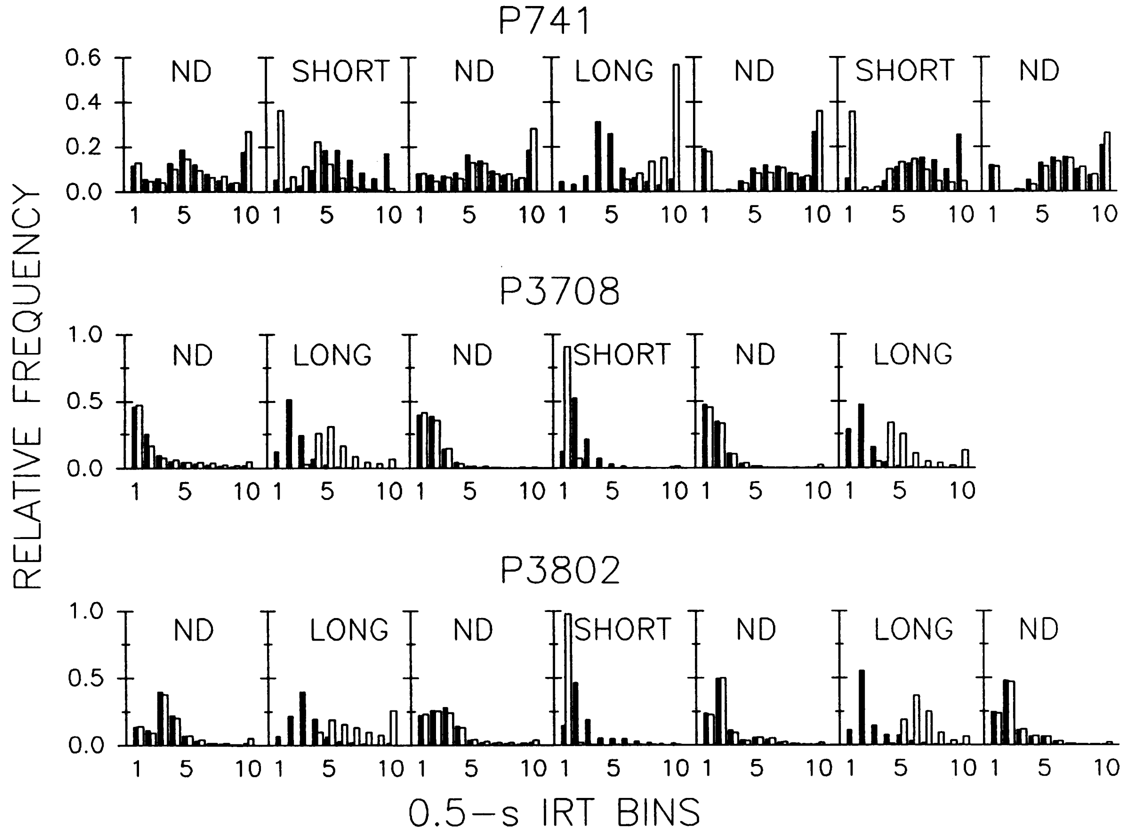

Fig. 3. Relative frequencies of overall (solid bars) and shocked (open bars) IRTs in successive 0.5-s IRT bins averaged over the last nine sessions of each condition for each subject in the second experiment. Bin 10 includes all IRTs ≥4.5 s. Condition labels indicate the nondifferential (ND) or differential (LONG or SHORT) IRT shock schedules.

scribed for Figure 1. Compared to the nondifferential schedules, the shocked IRT distributions shifted to the longer IRT bins during the long-IRT shock conditions and shifted to the shorter IRT bins during the short-IRT shock conditions. The shocked IRT distributions for the nondifferential shock conditions generally matched the shape of the overall distributions.

For P741 and P3802, overall IRT distributions (Figure 3) tended to shift to the longer bins during the short-IRT shock conditions and to the shorter bins during the long-IRT shock conditions. For P3708, the relative frequencies of long IRTs and the shortest IRTs were reduced during the first long-IRT shock condition. During the second long-IRT shock condition, only the relative frequency of the shortest IRTs was reduced. During the short-IRT shock condition, the relative frequency of the shortest IRTs was reduced.

The IRTs/Op transformations of the overall and shocked IRT distributions iterate the findings of the overall and shocked IRT distributions of Figure 3 and are not presented. The shocked IRTs/Op showed that the differential shock conditions shocked the specified classes of IRTs differentially compared to the overall IRT distributions. For example, long IRTs were shocked at more than 30 times their corresponding overall relative frequency for P3708 and P3802 during some of the long-IRT shock conditions. Generally, the overall IRTs/Op distributions tended to shift away from the IRT bins targeted for shock.

Table 2 shows that the effects on overall response rates were inconsistent. P741's response rates increased during long-IRT shock

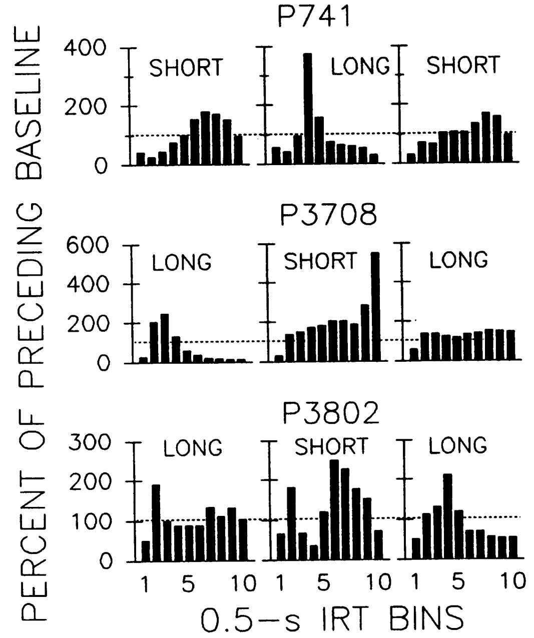

Fig. 4. Relative frequencies of overall IRTs for the differential shock conditions plotted as a percentage of the preceding nondifferential shock conditions in successive 0.5-s IRT bins averaged over the last nine sessions of each condition for each subject in the second experiment. Bin 10 includes all IRTs ≥4.5 s. Condition labels indicate the differential (LONG or SHORT) shock schedule. Dashed horizontal lines at 100% indicate no change from baseline.

conditions and showed little change during short-IRT shock conditions compared to the nondifferential shock conditions. P3708's response rate decreased in all differential shock conditions compared to the nondifferential shock conditions. P3802's response rates increased in the succeeding nondifferential conditions after all three differential conditions. Response rates decreased during the second long-IRT shock condition compared to both the preceding and succeeding nondifferential conditions.

Figure 4 provides overall IRT distributions of the differential shock conditions for each of the subjects plotted as a percentage of the preceding nondifferential baseline. Generally the targeted IRT classes decreased and the relative frequencies of IRTs toward the opposite end of the distributions increased.

Discussion

The differential punishment procedures differentially shocked long or short IRTs, depending on the condition. The resulting effect on the overall IRTs was punishment (i.e., the frequency of the targeted IRTs decreased). The relative frequencies of the shocked IRTs decreased and the relative frequencies of the IRT bins toward the opposite end of the distributions increased. These effects were consistent within and between subjects and add generality to previous reports (Galbicka & Branch, 1981; Galbicka & Platt, 1984; Sizemore & Maxwell, 1985) of the susceptibility of long IRTs to differential punishment; in addition, they demonstrate that short IRTs also are sensitive to punishment.

The punishment effects (i.e., decreases in the frequency of the targeted responses) were consistent at the level of 0.5-s IRT bins. The effects on overall response rates of the differential punishment contingencies were not consistent. The orderly changes in IRT distributions were not necessarily concomitant with response-rate changes. An analysis based solely on molar, sessional data would not reveal the systematic effects that were obtained. The present data suggest that a molecular level of analysis is essential to assess accurately the effect of molecular contingencies.

GENERAL DISCUSSION

These two experiments provide further evidence that IRTs are punishable response classes. The first documented the inherent delivery of shocks to long IRTs that occurs with VI schedules of punishment, and the second demonstrated that either long or short IRTs can be punished in ways consistent with effects on single responses.

In examining the molecular contingencies of the present experiments, the shock-probability-per-response variable discussed by Galbicka and Platt (1984) seems particularly relevant. Shock rate was relatively constant across all shock conditions, but shock probability per response varied as overall rates and IRT relative frequencies varied. As discussed above, the second VI shock condition in Experiment 1 was not as effective in punishing long IRTs as was the first VI shock condition. Given the relatively constant shock rate, this difference may have been due to the lowered shock probability per response produced by the progressively increasing response rates across the conditions of the first experiment. As response rates increased, the probability of shock for each response decreased, thus lessening the effectiveness of the shocks in sustaining response-rate suppression. More specifically, as overall response rates increased, the absolute values of the relatively long IRTs that were likely to be shocked decreased. As the absolute values of these likely-to-be-shocked IRTs became smaller, these IRTs became members of IRT classes that had higher and higher overall relative frequencies. That is, the values of the shocked IRTs became progressively closer to the mode and consisted of values of relatively frequent IRTs. The resulting punishment therefore became less differential, reducing the effectiveness of the punishment, and produced a ceiling on the punishment effects.

The notion of shock probability per response also is relevant to the second experiment. One implication of this variable is that there may be differential sensitivity to IRT punishment during low- versus high-rate responding. Anecdotally, patterns of responding across the individual sessions may be relevant. During the relatively low-rate "warm-up" periods at the beginning of the sessions, small but fairly consistent reductions in warm-ups (increases in short IRTs) occurred during long-IRT punishment conditions. The warm-up effects for the short-IRT punishment conditions were less consistent than those for the long-IRT punishment conditions. Possibly this was related to the higher relative frequency of short IRTs, which reduced the effectiveness of the punishers so that the effects on gross behavioral patterns were not as noticeable.

In addition to the possible effect of shock probability per response on punished responding, punishment intensity may affect response-unit size of punished responding. As shown by the data of Experiment 2, shock presentations affect the subsequent frequency of IRTs with durations similar to the IRTs contiguous with shock. Shock deliveries also may affect more remote IRTs. That is, shocks may suppress not only the contiguous IRT classes but also more remote IRT classes. The punished unit may not be a single IRT but a sequence of several IRTs. This temporal limit of effect may become greater (and include a longer and longer sequence of IRTs) as shock intensity increases. As shock intensity increases and these sequences become longer, the sequences probably would include IRTs of various lengths rather than consistently long IRTs such as those that occurred contiguous to the shocks during VI punishment in Experiment 1 (cf. Figure 1). If so, then for VI punishment schedules, as shock intensity increases, the consistent relation between shocks and relatively long IRTs is disrupted. At higher voltages, shocks will be delivered to relatively long IRTs less differentially. Such a process may have contributed to the lack of consistent IRT punishment effects during the later shock conditions of Experiment 1.

Perhaps most important, these experiments stress the value of considering the molecular processes that operate during the interface of behavior and contingency. These molecular processes may be indirect ones, inherent in the interaction of behavior and contingency (as in Experiment 1), or they may be directly scheduled (as in Experiment 2). This highlights the value of molecular analysis and consideration of functional unit size. During punishment procedures, exactly what is being punished? The anomalous, previously reported findings for VI schedules of punishment are anomalous only at the level of overall response rates. The present two experiments have shown that a priori notions about punishment effects based solely on overall response rates can be misleading. Analyses are best based on units that provide sensitive measures of the controlling variables of the behavior of interest. This adjustment of analysis to contingency may necessitate a match between the two, as in the IRT analysis of IRT contingencies in Experiment 2. In some cases, behavior may be differentiated at multiple levels (e.g., both long IRTs and single key pecks with VI schedules), and the level of analysis may need to be changed to provide the best measure of the mechanism of action of each particular parameter. For example, the effects of changes in shock rate of VI punishment schedules probably could be examined adequately through analysis of overall response rates. However, examination of the effects of more molecular variables involved in VI punishment (e.g., IRT punishment, shock probability per response, or shock intensity) may require a match of a molecular analysis to these variables. Finally, in cases in which the mechanism of action of a particular variable is unknown, multiple levels of analysis initially may be necessary to pinpoint the exact nature of the interaction of behavior and contingency.

These considerations of molecular processes and functional response units also relate to human behavior, for which the use of punishment procedures is controversial (e.g., Iwata, 1988) on both ethical and efficacy (LaVigna & Donnellan, 1986) grounds. Given the efficacy of punishment with nonhumans and the present data concerning the use of appropriate units of analysis, questions concerning punishment effectiveness with humans invite further analysis. It seems possible that in some cases of ineffective punishment in humans, only the analysis was ineffective. If punishment was scheduled in a way that was similar to a VI schedule, the ineffective punishment may have been ineffective only at the level of overall response rates. Long IRTs may have been punished. Consider the inappropriate behavior of a young child. It is unlikely that the behavior will be punished on every occurrence. Only some of the responses (and IRTs) will be punished by the parent. If the behavior is relatively frequent (maybe while playing with another child) some, but certainly not all, of the responses are likely to be punished. Compare this to the situation in which the child has not behaved inappropriately for a relatively long time. In the context of relative calm, an inappropriate response probably would be highly disruptive and would evoke the punishing response of the parent. Given that the punishment intensity is not high enough to suppress responding completely and punishment frequency remains constant, this scenario could result in almost all long IRTs being punished and relatively few of the short IRTs being punished (a situation analogous to the differential punishment of long IRTs). Such an arrangement could increase the overall response rates while effectively punishing long IRTs, and is an example of either ineffective or effective punishment depending on the unit of analysis.

Molecular contingencies of reinforcement have proved to be valuable in human applied work. Contingencies arranged for long IRTs have reduced the frequency of overeating (Epstein, Parker, McCoy, & McGee, 1976), misbehavior (Deitz & Repp, 1973, 1974), and caffeine consumption (Foxx & Rubinoff, 1979), and short IRT schedules have been used to increase oral reading rate (Wilson & McReynolds, 1973). The application of molecular analyses to punishment also could prove to be valuable by allowing the effective use of molecular punishment contingencies. These analyses could add differential punishment schedules to the techniques of the applied behavior analyst, and they could allow applied behavior analysts to analyze more completely the effects of punishment on human behavior. At the very least, data and analyses such as those provided here should increase the explicit questioning about what the functional response units are in both human and nonhuman behavior. Researchers also should be encouraged to analyze behavior at several levels of integration and to use the unit of behavior most appropriate to the situation.

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