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DISRUPTION OF A TEMPORAL DISCRIMINATION UNDER RESPONSE-INDEPENDENT SHOCK[1]

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The responding of rats was reinforced on one key after a 1-sec auditory stimulus and on a second key after a 5-sec stimulus. With errors punished by a short timeout, all subjects achieved a high level of accuracy. A chain of responses during the stimuli mediated the performance so that when the auditory signals were omitted accuracy decreased only slightly. Response-independent aversive stimulation superimposed upon this procedure both suppressed the total amount of behavior and reduced the accuracy of the discriminative performance, the intensity of the stimulus determining the error rate. The increase in errors under these conditions may have depended in part upon differential suppression of members of the response chain, but such suppression was not necessary, since error rate increased even in its absence. Furthermore, the locus of response disruption within the chain was not consistent from day to day either for any individual animal or across animals.

Some effects of aversive stimuli are specific to behavior that occurs in close temporal contiguity with the stimulus (such as escape behavior and response suppression by punishment). Other effects appear to be more temporally dispersed (such as long-lasting upset, and general reduction in food-intake or in discriminative stimulus control both within and between experimental sessions). Hearst (1965) reported that aversive stimuli have a generalized effect of breaking down a well-established discriminative performance. When either cued or non-cued response-independent shock was superimposed upon a multiple variable-interval extinction schedule of food reinforcement, responding during the extinction component was found to increase, although more reliably in the cued case. An apparently related finding is obtained when a conditioned emotional response (CER) procedure is added to an established differential-reinforcement-of-low-rates (DRL) performance (Blackman, 1967) in that the low rate of DRL responding increases during the stimulus correlated with shock. The Blackman (1967) study demonstrated discriminative breakdown primarily during the stimulus preceding shock, unlike Hearst's more generalized effect during stimuli not so correlated. In both cases, it is the rise in a low response frequency that is interpreted as breakdown of the discrimination. But the possibility exists that the aversive stimulation is merely exercising a greater energizing effect on low probability responding than on high response levels.

To resolve this question, the present experiment employed a discrimination in which a response on one key after a 1-sec auditory stimulus was reinforced and a response on a second key was reinforced after a 5-sec stimulus. Although responding developed during the stimuli at different rates on each key mediating the discrimination, the effects of response-independent shock upon the accuracy of the final response could be assessed independently of specific disruption of the mediating chains.

METHOD

Subjects

The free-feeding weights of six male albino rats (Charles River type CD), approximately 120 days old when the experiment began, were determined daily over two weeks, after which each rat was kept at 80% of its free-feeding weight through water deprivation.

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Apparatus

Two chambers (Scientific Prototype, Model 100), housed in sound-attenuating shells, were equipped with liquid reinforcement dispensers, 8-ohm Quam speakers, and two translucent response keys (Grason-Stadler, Model E8670A). The keys were 4.5 in. above the floor and 4 in. apart. Auditory stimuli consisted of white noise from a Grason-Stadler generator (Model 901B). Scheduling and recording were provided by a PDP-8 digital computer (Digital Equipment Corp.) with a specialized program written in terms of operant contingencies (Snapper, Knapp, and Kushner, 1967). Shocks consisted of 325 v ac, and were applied as a single sequential sweep across the 16 bars of the chamber grid, with current applied to each bar for about 20 msec (Snapper, 1966). Shock current levels, reported in the following section, were calculated on the assumption that the rats' resistances averaged 30 Kohms.

Procedure

All subjects were given daily 1-hr sessions with reinforcement consisting of 4-sec access to a 0.01-cc dipper cup filled with a mixture by volume of 50% water and 50% evaporated milk.

During the first two experimental sessions, each rat was trained to approach the dipper. In the third session, the left key was covered with black tape, and each subject was trained to press the right key after the white noise terminated. In this and all succeeding sessions, responses during the noise were never reinforced. The auditory stimulus was presented for 1 sec immediately after the end of reinforcement, and the first response after the noise ended produced the next reinforcement. After four successive sessions of this procedure, the right key was blocked and reinforcement was made contingent upon the first response to the left key after a 5-sec white-noise stimulus terminated. Again, responses during the stimulus, which began at the end of the reinforcement, were never reinforced. Altogether, seven sessions of training to the left key were given before the final stage of training began.

The terminal discriminative contingencies involved differential reinforcement for the appropriate response to the two keys, depending upon the duration of the immediately preceding auditory stimulus.

The details of this procedure are presented in the form of a state graph (Snapper *et al.*, in press) in Fig. 1. In this graph, conditions of stimuli and contingencies in effect throughout the experiment are shown by enumerated circles called states, only one of which is in effect at any time. Arrows leading from one state to the next show the response contingency or temporal requirement for the transition to new states with the accompanying requirement written above, or beside, the arrow. At the start of each session, State 1 ($1/S_1$ where S_1 represents the noise plus background stimuli) was entered. After 1 sec of the noise, during which responses had no effect, transition to State 2 occurred as shown by the arrow leading from State 1 to State 2. During State 2, S_2 represents the background stimuli of the chamber, minus the noise, and this state remained in effect until a response was made, either on the right or left key. If the right key was pressed, State 3 with its associated reinforcement was entered. After a 4-sec reinforcement, State 7 was entered and after 1.5 sec, either State 1 or State 4 began. If the left key was pressed, State 6 was entered, reinforcement was not presented, initiating the 15-sec delay before the next trial began. After both States 6 (error) and 7 (correct), initiation of State 1 or 4 as the next state was probabilistic with either transition being equally likely (indicated by 1.5-sec P, where $P = Q = 0.5$). If State 4 was entered, the noise was presented for 5 sec and, after the noise (State 5) a left-key response was reinforced; a right-key response was followed by the 15-sec timeout (State 6). Responses had effects only during States 2 and 5 (*i.e.*, after termination of the stimulus) and

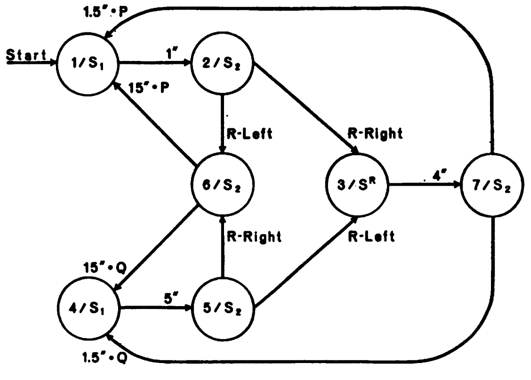

Fig. 1. State graph describing experimental contingencies in effect.

a non-correction procedure was used, in that after errors, the next duration could be either 1 or 5 sec.

In summary, then, a 1-sec and 5-sec noise were presented in random order with the former signalling reinforcement for right-key and the latter for left-key responses. Errors were followed by delayed onset of the next trial and only responses after noise led to reinforcement or timeout, responding during the stimulus having no scheduled effect. This baseline discrimination training was continued for three (F2, F7, and F9) of the six rats for a total of 61 sessions, and for the other three rats for 22 sessions. The last three sessions with each rat were taken to be a zero shock control value.

During the final phase of the experiment, five response-independent uncued shocks were delivered during each session. The interval between shocks ranged from 6 to 14 min with an average of 11 min in a random sequence, and shocks were presented independently of behavior so that they could fall during cues, reinforcements, or silent periods. Each subject was exposed to two consecutive sessions of this schedule at each of 15 shock values, starting at 0.5 ma and progressing in 0.5-ma steps up to the final value of 7.5 ma. Exceptions to this sequence, for reasons to be seen later, were: (a) the initial exposure to 0.5 ma for two sessions was followed first by one session with no shock, and then by two more sessions at 0.5 ma; (b) the two 3.5-ma sessions were separated by one non-shock day; (c) two sessions without shock were administered following the highest shock level of 7.5 ma; and, (d) the final session of the experiment was a no-shock one in which the auditory stimuli were absent but the reinforcement contingencies remained in effect.

RESULTS

Baseline performance. By the final three sessions of discrimination training, each rat was responding correctly in at least 95% of the trials (*i.e.*, the first response after a 1-sec stimulus was on the right key, and that after the 5-sec stimulus on the left key).

Although responding during the stimulus had no effect upon the scheduled contingencies, each subject developed a stereotyped pattern or chain of responses on the two keys during the noise. Table 1 presents distributions of the frequencies of responses on the two keys during successive 0.5 sec of the 5-sec tone for the final baseline session. The rats responded on the right key for the first 1 or 2 sec after stimulus onset, and then switched to the left key toward the end of the 5-sec period. During the session, the number of 5-sec trials in which at least one response occurred during the stimulus averaged 90.6% for the six subjects. The final experimental session omitted the noise but left all of the response contingencies in force. During this test, all subjects (except for F10 which had a low response rate) made more errors than on the preceding non-shocked session, but fewer errors than would be expected by chance. (Table 2).

The high level of accuracy maintained despite the omission of the auditory stimuli sug-

Table 1

Distributions of responses on each key (R = right, L = left) during the 5-sec noise, in successive 0.5-sec intervals. Note that when the stimulus terminated, a left-key response was reinforced.

Stimulus Sub-Intervals (10ths)	*Subjects*											
	F2		*F3*		*F6*		*F7*		*F9*		*F10*	
	R	*L*	*R*	*L*	*R*	*L*	*R*	*L*	*R*	*L*	*R*	*L*
1	232	0	11	0	23	0	92	0	6	0	10	0
2	339	0	60	0	57	0	158	0	16	0	46	0
3	269	0	157	0	51	0	103	0	19	0	84	0
4	114	0	103	0	41	0	76	0	7	1	97	0
5	34	0	25	4	7	0	14	0	5	22	12	0
6	6	0	7	14	1	2	7	0	2	30	1	3
7	4	2	0	22	0	18	3	1	0	30	1	9
8	2	5	2	15	0	53	0	2	0	46	0	24
9	3	14	1	24	0	119	0	11	1	89	0	53
10	1	46	0	37	0	187	0	55	0	156	0	134
Total No. of Responses	999	67	366	116	180	379	453	69	56	374	251	223

gests that the discrimination was primarily based upon the right-left sequence of responses during the stimulus. In sessions during which the cue was present all subjects, however, did not respond during the cue on about 10% of the trials in which they responded accurately after the stimulus. The normal performance, then, probably depended upon both auditory and response-produced cues. This point is further substantiated by the low level of responding noted during the timeout periods following errors in control sessions.

Table 2

Per cent correct responses on each key during the last unshocked session (Noise) and during the final session, when the noise stimuli were removed (No Noise).

Subject	*Left Key*		*Right Key*	
	Noise	*No Noise*	*Noise*	*No Noise*
F2	96.1	90.0	97.4	86.4
F3	91.3	84.9	89.3	90.1
F6	93.3	74.8	95.3	72.8
F7	89.4	56.9	98.7	90.6
F9	94.4	89.9	92.7	91.1
F10	0	66.7	100.0	86.9

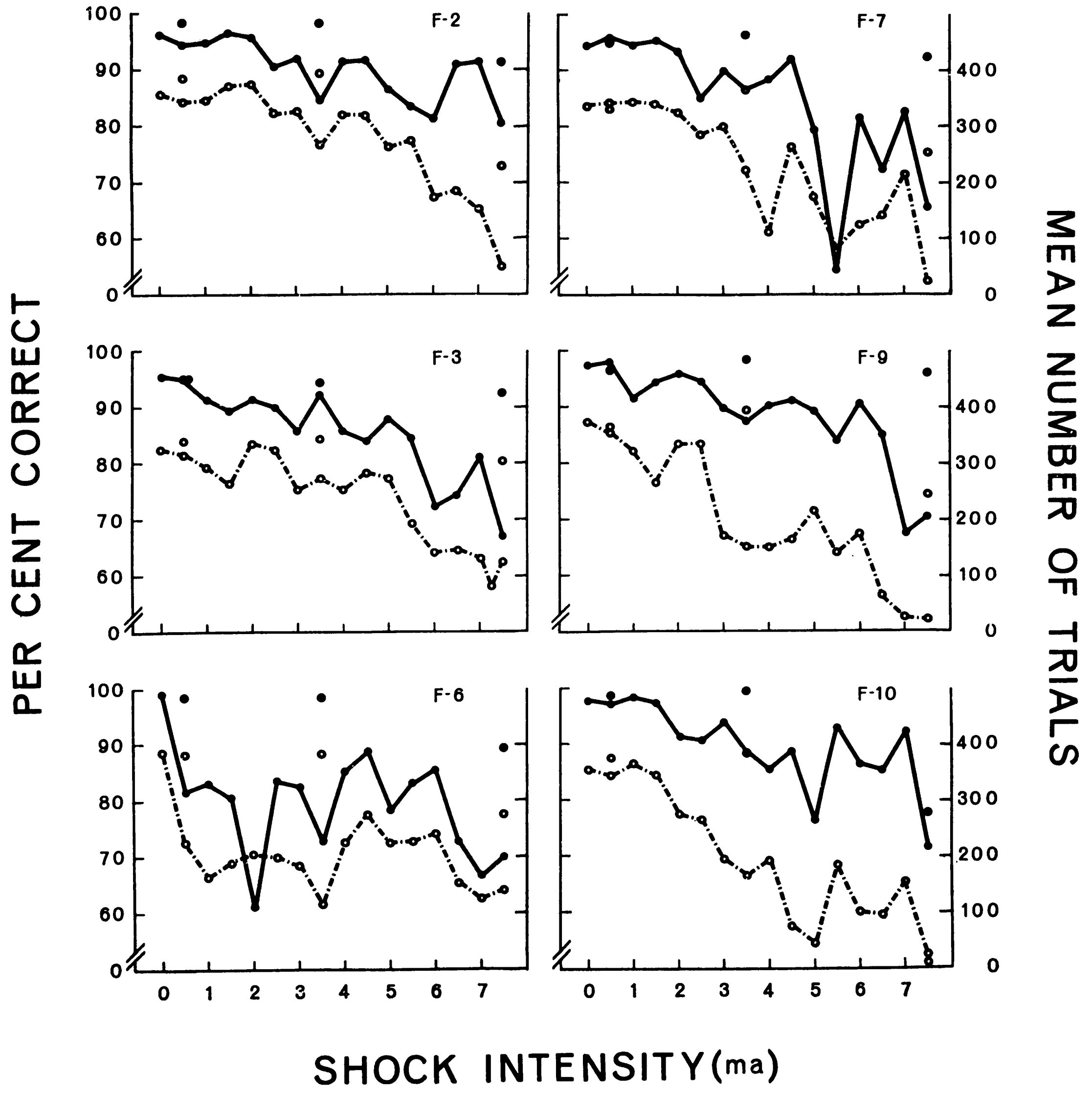

Fig. 2. Intensity of shock functions for the six subjects. Dashed lines represent mean number of trials (right-hand ordinate), while solid lines represent mean percentage of correct trials (left-hand ordinate). Unconnected filled and open circles represent interpolated non-shock sessions.

Effects of shock. Figure 2 presents for each subject the percentage of trials followed by correct responses and the average number of trials per session at each of the different levels of shock. The number of trials depended in part upon error rate (since each error was followed by a 15-sec timeout before the next trial began) and partly upon the latency of the first response after the stimulus. Figure 2 shows that, as shock intensity increased, the number of trials per session decreased for each subject, though at a different rate for the individual rats. Of special interest is the immediate increase in number of trials in the single shock-free session inserted at the 0.5- and 3.5-ma levels.

In general, the fall in percentage correct parallels that in the number of trials per session. Figure 2 indicates that the reduction in trial number was not completely determined by the increased error rate in any one session. For example, F7 showed considerable drop in the number of trials at 4 ma while error rate was relatively low. At other levels, including 5 and 7.5 ma, both measures were strongly affected by the response-independent shock. As said earlier, reduction in number of trials, when not correlated with an increased error rate, could have resulted from long response latencies after a few stimulus presentations, since the next trial would not occur until either a correct or incorrect response was made.

Recovery days (*i.e.*, shockless sessions inserted between shock sessions) produced a return toward both baseline discrimination accuracy levels and former total response rates, with the possible exception of the recovery session which followed the highest shock level of 7.5 ma. Visual observation of responding during response-independent shock sessions, along with the speedy recovery of baseline performance when shock was omitted, jointly indicated that errors did not occur in a session until the first response-independent shock was delivered. It appears, therefore, that the impact of shock upon discriminative performance was not conditioned, in the sense of being controlled by the specific paired stimuli, but rather was a general after-effect of the aversive stimulus.

Recordings of the chain of responses during the auditory stimulus permitted evaluation of whether increased errors arose from suppression of members of this chain (Blackman, 1967). Figure 3 plots the total number of responses on both keys during the auditory stimuli divided by the total number of stimuli per session. Increasing shock intensity slightly reduced responses during the stimulus for four of the animals, but produced no systematic trend for rats F3 and F9. Since the latter two subjects did make more errors as shock increased, suppression of the chain is not the only explanation of the increase in errors.

If the response-independent shock had exercised a consistent effect on the chain of responding during the stimulus (*i.e.*, had disrupted the chain in a consistent way such as fixation of responding on one key), then the percentage of errors made on one or the other key could be expected to demonstrate that consistency. These data, however, showed little consistency, either within or between subjects, as shock level increased. Although the average result for the group before shock was administered was close to 50%, some subjects made most of their errors after the shorter 1-sec stimulus and some after the longer 5-sec stimulus. As shock level increased, all subjects, except F2, sometimes made more errors on the right and sometimes on the left key. F2 tended throughout to make more errors, after the 5-sec noise (by pressing the right key), and it also showed the smallest increase in number of errors of all subjects. Distributions of the response frequencies on the two keys during the 5-sec stimulus (of the sort shown in Table 1) were also constructed for the shock sessions. These records also revealed little consistent change, thus substantiating the lack of systematic effect upon the chain of responding during the white-noise stimuli by the free-shock.

DISCUSSION

One feature of the baseline performance of the present experiment was the development of a measurable chain of responses that mediates the temporal discrimination. Although several recent experimenters (Catania, in press; Reynolds and Catania, 1962; Stubbs, 1968) have reported discriminations based on temporal aspects of a single stimulus with accuracy comparable to that of the present study, they have not noted mediating behavior. The present finding of an overt, stereotyped chain

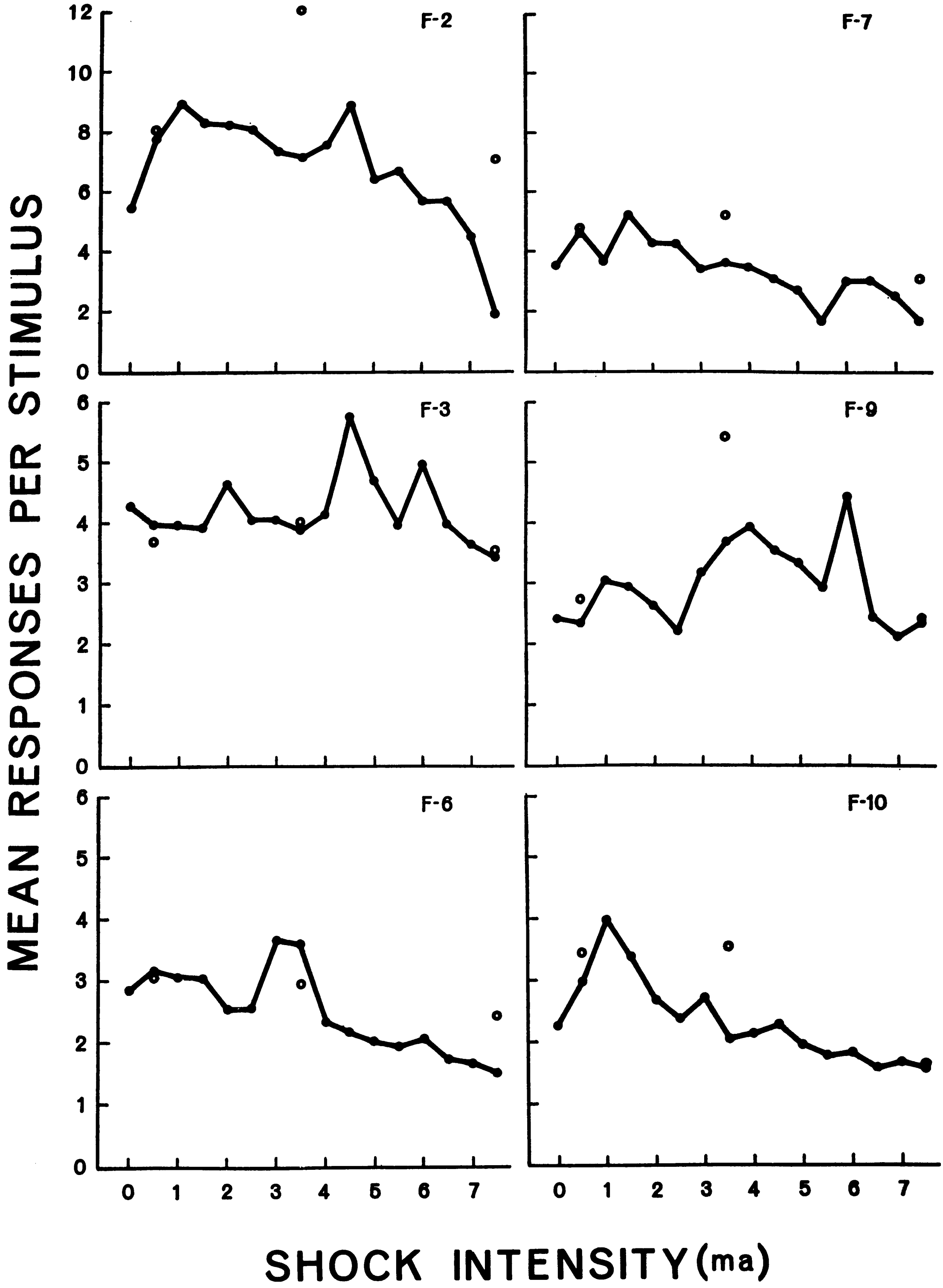

Fig. 3. Average number of responses per stimulus as a function of shock intensity. Open circles represent interpolated non-shock sessions.

during the auditory stimulus lends support to the suggestion that response chains do mediate some, if not all, temporal discriminations (Wilson and Keller, 1953; Rilling, 1967). The chain of responding that developed during the present experiment probably could have been eliminated by punishing responding during the stimulus, but this need not obviate the development of idiosyncratic "superstitious" responding not involving key presses. In terms of observing such chains it seems advantageous to permit them to develop toward the measured keys as in the present case.

The present results established that response-independent shock can increase error rate in a temporally ordered performance, and that the effect varies with the level of shock intensity. The procedure of gradually increasing shock intensities probably reduced the total amount of response suppression (Sandler, 1964), and may also have limited the total error rate. Furthermore, the increase in number of errors did not stem from differential suppression of the members of the chain of responses (Fig. 3): two of the six present rats showed no such suppression and the remaining four showed limited reduction in the number of responses per noise. We found little consistency among subjects in just where in the chain the errors occurred.

Unlike Hearst's (1965) study, where discriminative breakdown was related to the increase in rate of a previously low probability response, the present experiment indicated that a stimulus discrimination involving differential responding to two operanda may be disrupted by response-independent shock. One feature of the discriminative breakdown in both the present and Hearst's (1965) studies was the speed of recovery of performance when response-independent shocks were omitted. Apparently, the primary effect of an aversive stimulus does not become conditioned to the general experimental stimuli, but rather occurs only if the shock is delivered. This argues for the effect being a generalized unconditioned disruption of the discrimination rather than a conditioned suppression or facilitation of any particular part of the mediating response chain. Perhaps relevant to this point is the general procedural difference between the present study (as with Hearst's 1965 noncued group) and those of Blackman (1967), Migler and Brady (1964), and Kruper (1968). The latter experiments were primarily concerned with localized discriminative breakdown confined to the stimulus preceding shock. The specific sort of discriminative breakdown reported in those studies might depend upon the presentation of the pre-shock stimulus, for even in Hearst's (1965) cued group responding during the cue was abolished. However, Hearst's (1965) generalized effect (outside of the pre-shock stimulus) does appear to be more regular than ours, perhaps due to the simpler discrimination used as baseline.

An experiment that reported inconsistent effects of uncued but contingent shock is that of Edwards, Dubiner, and Crow (1967), in which a response-contingent punishment was delivered in the middle of a response chain requiring a fixed number of responses on one lever before a single response on a second lever was reinforced. The variability of runs of responses on the first lever increased under punishment but rapidly returned to unpunished levels when punishment was discontinued. The effect of punishment, in other words, was to cause breakdown of an inconsistent nature; *i.e.*, sometimes run lengths increased and sometimes decreased as against unpunished performance.

The present study and Hearst's (1965) found breakdown occurring under response-independent shock (but Migler and Brady, 1964, and Kruper, 1968, found little evidence of discriminative breakdown when cued response-independent shock was superimposed upon a complex discrimination). Hearst (1965) also observed similar, but smaller, effects under punishment, and Edwards *et al.* (1967) corroborated the latter finding. Thus, although there is still some uncertainty about the factors which produce breakdown of discrimination under aversive stimulation, the present study demonstrated that it is related to the variable of shock intensity under response-independent shock.

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