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VARIABLE-INTERVAL ESCAPE FROM STIMULI ACCOMPANIED BY SHOCKS[1]

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Individual performances of three rats were examined under a procedure in which steady rates of bar pressing were maintained by conditioned aversive stimulation. Originally neutral visual and auditory stimuli were accompanied by widely and irregularly spaced pulses of shock; they were terminated on a variable-interval schedule by pressing a bar. The contingencies between behavior and shock were also duplicated in a control procedure in which no visual or auditory stimuli were provided. Pressing observed under the control procedure was attributed to differences in the aversiveness of pressing and nonpressing behavior engendered by differences in the incidence of shock following the two classes of behavior. Increased rates with visual and auditory stimuli were attributed to termination of conditioned aversive stimulation. Control rates declined more rapidly than did experimental rates as the mean interval between successive shocks was lengthened; both rates tended to decline when less than 60 sec was allowed as time out from shocks following the successful response. In the control procedure, discrimination between the continuation and discontinuation of the shock series, as measured by relative rates, depended on the relative length of the interval between shocks and the time-out period. Regular warm-up accelerations in rate were noted following an initial delay in responding at the beginning of each session. The length of time required for the warm-up depended on the length of the mean interval between shocks, indicating that exposure to a certain amount of shock was required to establish a supporting state for the observed performance.

Conventional techniques for studying "fear," "anxiety," or conditioned aversive stimulation (*e.g.*, Kalish, 1954) separate the procedure for testing the stimulus from the procedure for making it aversive to the subject. Measurements of the effectiveness of the stimulus are essentially episodic, since the tests can be conducted only during the process of decline from some previously established level. The purpose of the present investigation was to make available a technique for measuring conditioned aversive stimulation that is continually maintained in effectiveness by further pairing with shock. With such a process, continued measurement of a stable state is possible over an extended period of time.

METHOD

Subjects

Although a number of animals have been studied with the present procedure, the data here reported were obtained from three male white rats tested under a variety of parametric settings. Rat A was approximately 12 months old when first trained and 21 months old when death terminated its data; B was 7 months when trained and 23 months when the last data were collected; and C started at 9 months and died at 22 months. The animals had free access to food and water between sessions.

Apparatus

The experimental box was 9.875 in. long, 5.625 in. wide, and 6.75 in. high. The bottom consisted of five lengths of 0.625-in.-diameter brass tubing, the side walls of aluminum, and the top of Plexiglas. A cross-bar 5.25 in. long and 0.375 in. in diameter was mounted 4 in. above the surface of the grid at one end of the box. It required a force of 33 g and a downward travel of 0.25 in. to activate the recording and programming system. The experimental box was shielded from external stimulation by a lightproof and sound-resistant chamber, furnished with a 15 CFM blower to circulate the air and prevent the condensation of moisture on surfaces intended to be nonconductors of electrical current.

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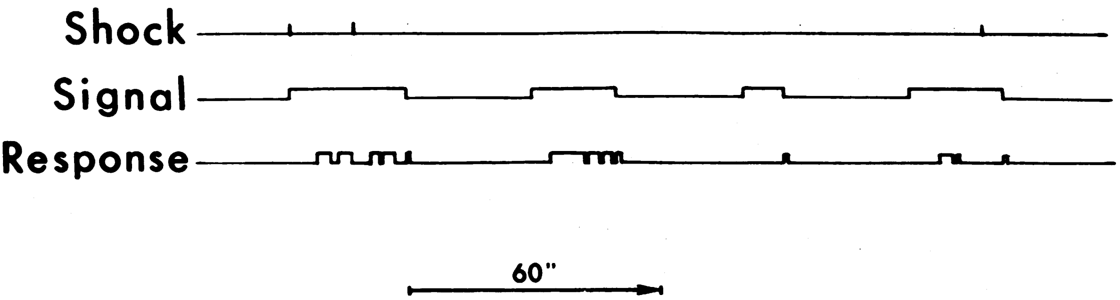

Fig. 1. Segment selected from a polygraph record to illustrate the basic procedure. The presence of each event in time is indicated by the upward displacement of the corresponding pen.

The shock was delivered through the five lengths of tubing that served as the floor grid and through the walls and bar, which together served as the sixth electrode. A droppings pan about 2 in. below the grid was also electrified. When shock was delivered, the animal received one 0.05-sec pulse for each electrode with which it was in contact, as the grid scrambler switched each momentarily to a polarity opposite that of the others. Within a wide range of subject resistance, the stimulator delivered 2 ma of half-wave rectified direct current (Dinsmoor, 1960, 1961). A tone used to distinguish the two experimental conditions was estimated to be approximately 500 cycles in frequency and about 80 db SPL. The corresponding light stimulus was provided by a 2-watt neon bulb (NE-34) flashing about once per second.

Procedure

The general procedure may be illustrated by a segment from a polygraph record reproduced in Fig. 1. The presence of each type of event in time is indicated by the displacement of the corresponding pen. A succession of irregularly spaced pulses of shock is initiated, which may or may not on a given session be accompanied by a signal light or tone; after the lapse of a predetermined but variable interval of time (mean length 30 sec), escape is made possible; the next depression of the bar terminates both the signal, if used, and the series of shocks for a fixed interval of time (time out). Then the cycle is repeated.

Before the final data were collected, each animal was trained for a number of sessions with signals and without signals and with a variety of mean intervals between shocks; during this time the time-out period was fixed at 60 sec. The settings for these variables during the experiment proper were as follows: (a) The mean interval between the shock pulses was tested at values of 7.5, 15, 30, 60, and 120 sec. (b) The length of time the signal and the shock series remained off, once terminated, was tested at values of 15, 30, 60, 120, and 240 sec. (c) Finally, the tone and the light were presented during some of the experimental sessions, but not others. For Animals A and B the tone indicated that the shock series was in effect, even though no shock might recently have been received, whereas the light indicated that no shocks were to be presented; for Animal C the roles of these two signals were reversed.

The experimental sessions lasted 10 hr, but because of warm-up effects which are described below, the terminal rate data are based on the last 7 hr of each session. Each animal was given 2 to 3 free days between sessions. Experimental conditions were shifted from session to session to fill in the main cells of the desired matrix in an irregular sequence that varied from one subject to another. Most of the plotted points are means of two or more determinations.

RESULTS AND DISCUSSION

Warm-up

Despite quantitative variations among animals and among experimental conditions, the general pattern of behavior within the session was completely regular. At the beginning of the session the animal failed for some time to respond; in extreme cases, this delay lasted for an hour or more. When the animal did begin to respond, its initial rate was low,

Table 1

Mean Time Elapsed (in Minutes) Before First Response in Session

Mean Seconds Between Shocks	*Rat A*		*Rat B*		*Rat C*	
	No Signal	*Signal*	*No Signal*	*Signal*	*No Signal*	*Signal*
7.5	1.48	0.58	5.33	2.92	8.26	3.42
15	2.27	2.87	6.78	8.42	14.46	9.93
30	4.64	5.50	14.17	8.29	26.36	13.38
60	12.42	15.26	19.62	9.19	31.38	27.56
120	8.17	17.63	17.35	9.64	46.92	50.88

gradually accelerating toward an asymptotic level determined by the experimental conditions for that session. This pattern was characteristic of all rats exposed to the procedure, including several pilot animals that are not considered in the present report. It was quickly established and never disappeared with further training, although Rats B and C, for example, were each tested for more than a hundred sessions. The only sessions in which this warm-up pattern was not obvious on the cumulative record were early in the animal's training, or in a few cases in which the 7.5-sec interval was used between shocks and the acceleration was relatively rapid.

The relationship of the warm-up pattern to the experimental variables is fairly simple. As Table 1 shows, the length of time the animal waits before making its first response depends on the mean interval between shocks. The more often the animal is shocked, the more quickly it responds; the longer the time between shocks, the longer it waits. The length of this wait is not quite proportional, to be sure, to the time between shocks; the animal will respond relatively early, after fewer

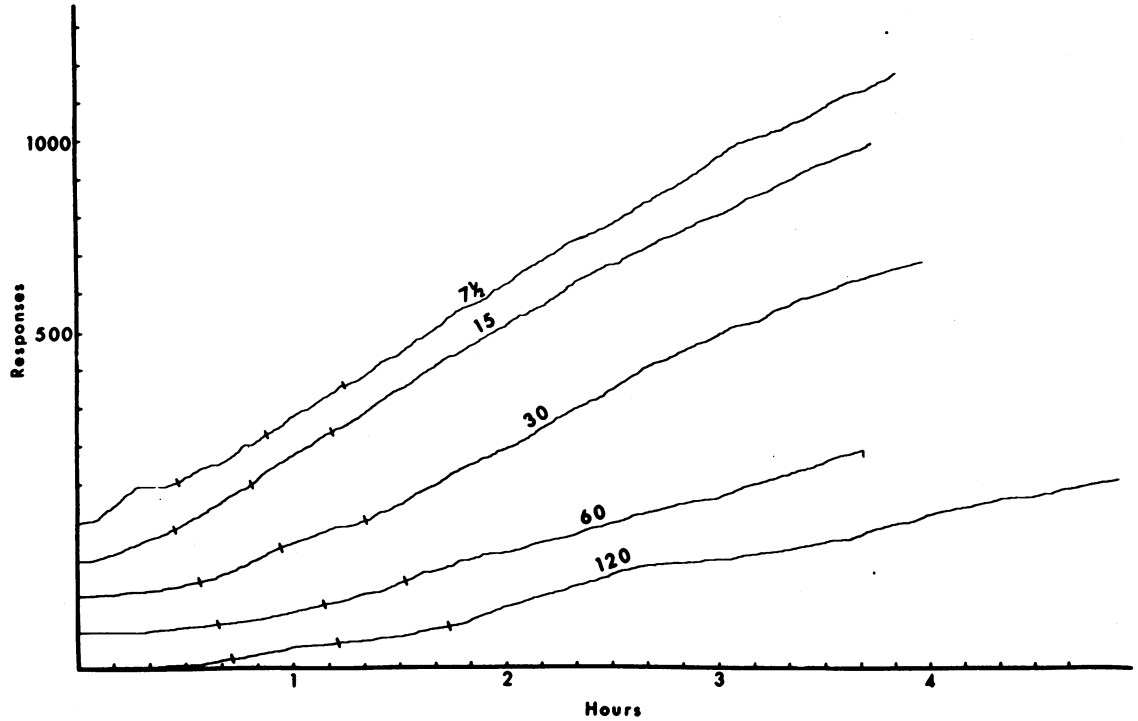

Fig. 2. Cumulative-response curves obtained for five sessions with Rat A in which the mean interval between successive shocks was varied from 7.5 to 120 sec but the length of the time out was held constant at 60 sec. Light and tone were used. The recorder stopped during the time-out interval. The cross hatches mark the end of the first, second, and third hours of session time.

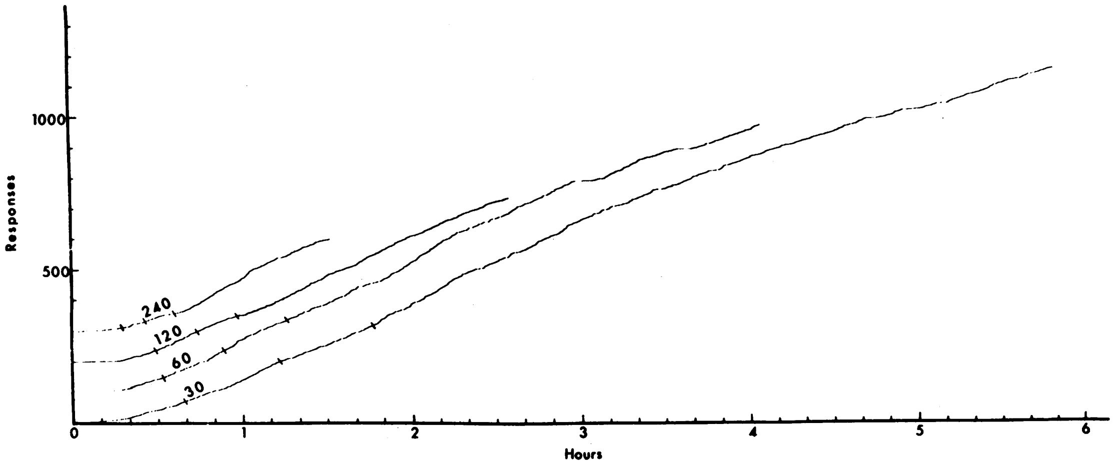

Fig. 3. Cumulative-response curves obtained for four sessions with Rat B in which the mean interval between successive shocks was held constant at 15 sec but the length of the time out was varied from 30 to 240 sec. Light and tone were used. The recorder stopped during the time-out interval. The cross hatches mark the end of the first, second, and third hours of session time.

shocks, if these are widely separated in time. It is quite possible, however, that this tendency to respond relatively early with more time between shocks is merely a reflection of the increased opportunity to respond with the increase in time allowed, once a given level of probability has been attained.

As Fig. 2 illustrates, the rate of acceleration from the initial response to the final level of performance is also a function of the frequency with which the shocks are delivered. This relationship has been replicated repeatedly with each of the animals.

The length of the time-out period following the successful response does not, however, seem to be an important factor. With the time-out periods themselves omitted from the cumulative record, the curves rise in almost identical fashion, as shown in Fig. 3. It is evident that time, *per se*, is not on important factor in the warm-up process, since the interpolation of additional time without shock has no discernible effect, either to speed up the process or to slow it down. This indicates two things: first, exposure specifically to the shocks is required for the warm-up process, not merely exposure to the general experimental situation. (This is not an adaptation to novel stimuli or the type of warm-up observed in studies of motor skill.) Second, the effect produced by these shocks is relatively slow to decay in time.

It seems evident, then, that a certain amount of exposure to the shock is required to build up some state of the organism that is a necessary support or precondition for the type of performance we have been considering. Although occasional warm-up effects were observed in an earlier study of escape from shock (Dinsmoor & Winograd, 1958), the effect was not regular; probably, it was obscured on many of the sessions by the temporal massing of the individual pulses of shock and the consequent rapidity of the approach to a final level of responding. Sidman (1953b) noted a similar warm-up with a shock-postponing avoidance schedule, but commented only that its length "appeared to be a function of the current schedule" (p. 256). Perhaps this is the activation sought by drive theorists in aversively maintained behavior.

Terminal Rates with No Signal

The lower half of Fig. 4 shows the terminal rate of responding during the series of shocks in the case where no signal is provided. A similar picture is revealed for all three animals. The mean interval between shocks in the series is an important determinant: in most cases, the more frequently the shocks are presented, the higher is the rate of responding.

Beyond 60 sec, the length of time for which the series of shocks is terminated does not seem to be important: the curves lie close together, suggesting replications of essentially the same function. But when the length of the time out is reduced to 30 sec, the rates of responding for Animals A and B tend to drop off; and the third animal, C, shows the same effect when the time is further reduced to 15 sec. Actually, the numerical data cannot tell the whole story here, since the rate of responding no longer remains stable throughout the session at these values but tends to decline from early levels as the session progresses. To protect the animal from injury, in some cases it was removed from the apparatus before the allotted time was up; presumably, rates for completed sessions would be lower still than those reported.

When the successive pulses of shock are spaced as far apart in time as in much of the present work, it seems meaningless to continue to appeal to termination of the shock, in the sense of something that has been continuously present and is then abruptly removed, as the reinforcing event. The change is quite gradual. The animal cannot immediately discriminate the discontinuation from the continuation of the shock series, because this discrimination is logically dependent on the time that has elapsed since the last shock. Some gradual change in conditions following the termination of the shock series may possibly be involved, but it seems more plausible to appeal to the relative incidence of shock pulses following two classes of behavior, bar pressing and behavior incompatible with bar pressing. Both classes of behavior are followed by shock on occasion. But during the shock series bar pressing is favored by a special contingency: some presses lead to a discontinuation of the series and are therefore selectively exempted from ensuing shocks. Thus, the stimuli associated with a more frequently shocked class of behavior are terminated by each pressing of the bar (Hefferline, 1950; Schoenfeld, 1950; Sidman, 1953a); no additional reinforcement necessarily occurs when the series of shocks is terminated.

As we have already noted, the performance tends to suffer when the time out is reduced to values of 30 sec or less. When the interval between shocks within the series is also short, the mean of all intervals between shocks is small, and it can be argued that the animal's performance is depressed by the sheer frequency of shock to which it is subjected. But when a short time out combined with longer intervals between shocks, this explanation no longer holds.

The remaining dimension to be considered is the relation between responding and subsequent shock, specifically between the press that terminates one series of shocks and the

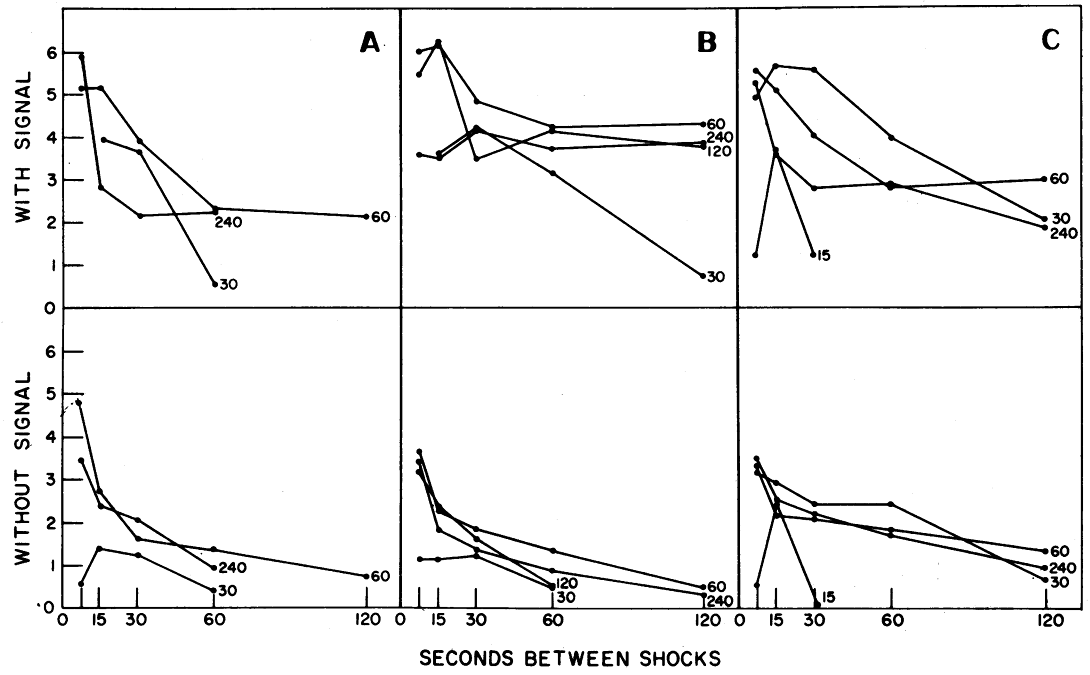

Fig. 4. Families of curves showing the mean rate of bar pressing by each rat as a function of the mean interval between successive shocks. The values identifying each curve represent the number of seconds for which the shocks remain off when terminated (time out); and A, B, and C are individual rats.

shock that initiates the next, after the time out has ended. It is not entirely clear how a shock following the response by 30 sec or more can make effective contact with the animal's behavior. But if we treat the present procedure as a variable-interval scheduling of Sidman's shock-postponement procedure, this result corresponds to the finding (Sidman, 1953b) that the shock-postponing response declines in rate whenever the interval between the response and the shock (R-S interval) drops substantially below the interval between shocks in the absence of the response (S-S interval). (See also Sidman, 1954.)

Terminal Rates When Signals Are Provided

When arbitrary stimuli that appear and disappear with the initiation and termination of the shock series are added to the program, a further source of reinforcement is provided. These stimuli, like those that are inherently associated with nonpressing behavior, are also terminated by pressing the bar. As a comparison of the corresponding points in the upper and lower halves of Fig. 4 shows, higher rates of responding are maintained when these artificial stimuli are provided. Again, the rate of responding is highest when the shocks are closely spaced within the series, but the decline in rate is more gradual as the interval between successive shocks is lengthened. A substantial performance may be maintained with as long an interval as 120 sec intervening between the shocks. Again, 60 sec seems to be an adequate length for the time-out period, but the rate tends to drop when lower values are used.

The poor performance with short time outs is easier to explain than it was in the no-signal case. The length of the time out determines the frequency with which shock is associated with the absence of the signal. When the number of shocks per unit of time becomes greater in the absence of the signal than in its presence, the animal is caught between the frying pan and the fire; there is no longer anything to be gained by terminating the signal, and the rate of pressing is reduced.

In general, then, the proposed technique for maintaining behavior with conditioned aversive stimulation appears to be an effective one; but it is contaminated by responding that is maintained even under "control" (no-signal) conditions by differences in the probability of shock following different classes of behavior. This contamination is relatively

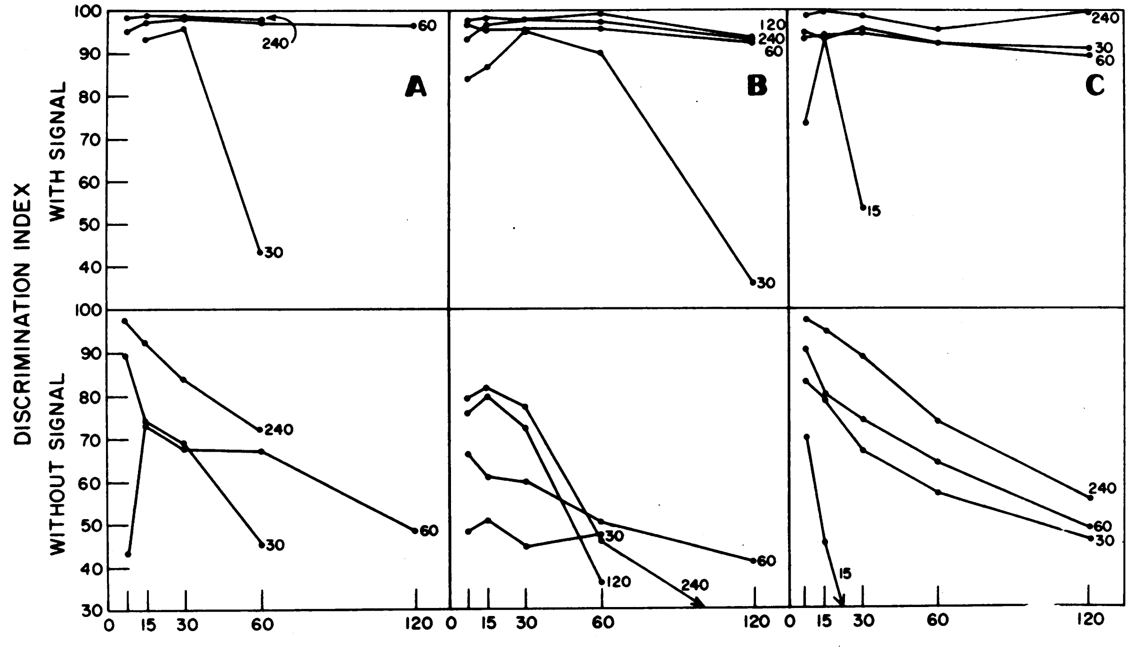

Fig. 5. Families of curves showing mean level of discrimination (100 X rate during shock/sum of rates) as a function of mean interval between shocks. The values identifying each curve represent the number of seconds for which the shocks remain off when terminated (time out); and A, B, and C are individual rats.

small when long intervals intervene between successive shocks in the series, but rates of responding may also be relatively low in such cases; more severe shocks or a more sensitive organism may be needed to ensure satisfactory performance under these conditions.

Discriminations

It we treat the presence and absence of the shock series as a pair of stimulus conditions that can be discriminated by the animal, we may calculate an index showing the accuracy of this discrimination. Correcting the conventional percentage measure (*e.g.*, Dinsmoor, 1952) for inequalities in the amount of time the animal spends in either condition, we divide the rate during the shock series by the sum of the two rates and multiply by 100.

First, note that when light and tone signals are provided to distinguish between the two conditions (upper half of Fig. 5), the index is maintained at a high level, even with long intervals between the shocks. For time-out periods of 60 sec or longer, the index drops below 90 only once for any subject at any shock interval. For Animals A and B, the curves dip lower when the time out is reduced to 30 sec, and for C when it is reduced to 15 sec. But at these values the entire performance has collapsed.

The relationships observed in the lower half of Fig. 5, for discrimination without signals, are much as would be predicted from the assumption that the animal's discrimination is based on the time that has elapsed since the last shock. First, when the shocks are spaced only 7.5 sec apart, the discrimination is usually good—the animal responds much more often in the presence of the shock series than in its absence. When the shocks are spaced further and further apart, however, the efficiency of the discrimination perforce declines; with a mean interval of 120 sec between shocks, there is little evidence for its continued existence. The tendency for the index to drop below 50 at some points, *i.e.*, for the calculated rate during the shocks to drop below its nonshock counterpart, is probably related to the fact that at low over-all rates the experimental contingencies impose an inverse relationship between continuation of the time sample for the shock series and responding by the animal. The second relationship to be noted in this set of curves is that the animal can distinguish the two conditions more and more accurately as the length of the time-out interval increases. In other words, the relative rates are determined by the relative lengths of the two intervals involved.

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