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# INTEGRATED DELAYS TO SHOCK AS NEGATIVE REINFORCEMENT[1]

PAUL LEWIS, EDWARD T. GARDNER, AND LARRIE HUTTON

OHIO UNIVERSITY

Rats were shocked at the rate of two per minute until they pressed a lever. In Experiment I, shocks were delivered at variable-time intervals averaging 30 sec; in Experiment II, shocks were delivered at fixed-time intervals of 30 sec. A response produced an alternate condition for a fixed-time period. The shock frequency following a response, calculated over the whole alternate condition, was two per minute. The pattern of shocks in the alternate condition was controlled so that the first shock occurred at the same time as it would have occurred had the response not been emitted; the remaining shocks were delayed until near the end of the alternate condition. Bar pressing was acquired in both experiments. This finding is not explained by two-factor theories of avoidance and is inconsistent with the notion that overall shock-frequency reduction is necessary for negative reinforcement. The data imply that responding is determined by the integrated delays to each shock following a response *versus* the integrated delays to shock in the absence of a response.

*Key words:* aversive control, avoidance, delayed shock, shock frequency, bar press, rats

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A response on a free-operant avoidance schedule (Sidman, 1953) interrupts for several seconds (RS interval) a series of brief shocks spaced a few seconds apart (SS interval). A single response has two effects. It introduces a delay between the response and the next shock, and it reduces the overall frequency of shocks. Several investigators have attempted to determine which of the two, delay or reduced frequency, is necessary and which is sufficient to produce responding.

Lambert, Bersh, Hineline, and Smith (1973) presented rats with a 10-sec stimulus followed by five shocks. A response during the stimulus produced one immediate shock, but caused the five shocks at the end of the stimulus to be omitted; thus, a response resulted in a decreased delay to shock and an 80% reduction in the total number of shocks. Several animals showed increased shuttle responding under this procedure; two rats, however, showed no acquisition of a bar-press response. Lambert *et al.* (1973) suggested that, overall, these results support the view that shock-frequency reduction is a sufficient condition for the acquisition of some responses.

When Bolles and Popp (1964) investigated the influence of shock-frequency reduction without delaying the first shock, shock-frequency reduction was not sufficient to produce responding. Each response was followed by the next shock due from the SS interval timer before the RS interval began. Of the 14 rats studied with this procedure, none acquired consistent avoidance behavior. Neither Bolles and Popp nor Lambert *et al.* found bar-press acquisition if the first postresponse shock was not delayed, implying that an immediate postresponse delay to shock may be necessary for the development of bar pressing.

Other investigators have examined the role of postresponse delay to shock. Overall shock frequency was held constant and only postresponse delay to shock was varied in Hineline's (1970) procedure. When a bar press delayed a single shock for 10 sec, but left the total number of shocks unchanged, the bar press was acquired. Hineline also found that responding stopped when it led to a 10-sec delay to shock accompanied by a shock-frequency increase. Gardner and Lewis (1976) presented shocks at variable times averaging two shocks per minute (VT 30-sec). A response activated a 3-min alter-

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nate condition during which the rat received a series of six shocks with a delay of 10, 88, or 165 sec. With overall shock frequency held constant, rats acquired the response. Acquisition was also found with a 100% increase in shock frequency, if shocks were delayed 150 sec after the response. Thus, delay to shock has been found sufficient, in the absence of shock frequency reduction, to reinforce behavior negatively.

Either delaying the first postresponse shock or reducing the total number of shocks appears to reinforce responding. The present experiments sought to determine whether delaying some shocks reinforces bar pressing, when *neither* the first shock is delayed *nor* the total number of shocks reduced.

## EXPERIMENT I

### Method

*Subjects*

Four female albino rats of the Sprague-Dawley strain purchased from the Holtzman Company were 90- to 120-days old when first introduced into the experiment. Each was experimentally naive and housed individually with free access to food and water.

*Apparatus*

The chamber was a two-lever operant-conditioning unit 24.2 cm long, 30.5 cm wide, and 24.1 cm high. The 0.48-cm stainless-steel bars in the grid floor were perpendicular to the wall on which the response levers were mounted and were 1.6 cm apart center to center. A clear plastic ceiling, 0.6-cm thick, was mounted 10.8 cm above the grid bars and 2.9 cm above the response levers. This ceiling kept subjects in contact with the grids by preventing rearing and jumping. The two side walls were clear plastic; the front and back walls were stainless steel. The chamber was enclosed in a sound-attenuating box, and 75-dB white noise was on throughout all sessions. General illumination was provided by two houselights mounted at the top and to the rear of the chamber. Onset of the white noise and houselights signalled the beginning of the experimental session; offset of the noise and houselights signalled the end of the session. Two rat levers requiring approximately 20 g (0.2 N) to depress, were mounted on the front wall 2.9 cm from each side and 7.9 cm from the grid bars. Depression of either bar served as a response. Allowing a response on either lever increased the operant level of responding and increased the probability that subjects would make contact with the contingencies. A response activated a clicker (86 dB, 10 Hz) and three translucent jewelled lights, 1.3 cm in diameter, for 3 min. The jewelled lights, 1.4 W, were centered 5.7 cm above the levers with the outer two lights centered 5.0 cm from each side wall and the third light midway between the outer two. A BRS solid-state shock source delivered 50-mW shock for 0.3 sec to grids, front and rear walls, and response bars. Solid-state switching circuits housed in an adjacent room controlled events.

*Procedure*

Subjects were tested for 6 hr every other day. All variable-time intervals were generated from Fleshler and Hoffman (1962) tables. If the rat failed to respond, it was shocked at irregular time periods averaging one shock every 30 sec. For 2.5 sec following the onset of each shock in the imposed condition, responses were ineffective in producing the alternate condition. All other responses on either lever in the imposed condition produced a 3-min alternate condition, together with correlated stimuli (clicker and jewelled lights). Responses in the alternate condition were recorded, but had no effect. At the end of 3 min, the alternate condition terminated, and the VT 30-sec shock schedule was re-instated.

*Experimental treatment 1.* The alternate condition contained the next scheduled shock from the VT 30-sec schedule and a train of five shocks, 1 sec apart, beginning 170 sec after the onset of the alternate condition. From the termination of the shock train to reinstatement of the imposed condition, the elapsed time was 5 sec, during which no shock was delivered.

*Experimental treatment 2.* Again, the alternate condition contained the next scheduled shock from the VT 30-sec shock schedule and a train of five shocks. However, during the second exposure to the experimental treatment the train of five shocks occurred 160 sec after the onset of the alternate condition. The time from termination of the train of shocks to the re-instatement of the imposed condition was increased to 15 sec during the second exposure to the experimental condition. We increased this interval to minimize the possibility of postshock responses after the shock train continuing into the imposed condition.

*Control.* The alternate-condition shock schedule was identical to the imposed-condition shock schedule. During both conditions, shocks were delivered on the same VT 30-sec schedule. Responses during the "imposed condition" produced the clicker and lights for 3 min.

*Order.* The order for two subjects (DV 1 and DV 2) was control, experimental 1, control, and experimental 2; for two others (DV 3 and DV 4), the order was experimental 1, control, experimental 2, and control. Subjects were continued until per cent of time in the alternate condition appeared approximately stable for three sessions under each condition. Stability was determined by inspecting cumulative records and figures showing per cent time as a function of sessions.

## Results

Figure 1 shows per cent of total session time spent in the alternate condition for the last three sessions of exposure to each treatment for Subjects DV 1, DV 3, and DV 4. When the experimental treatment was in effect, all three subjects spent large percentages of time in the alternate condition; when control was introduced, for all three subjects, time in the alternate condition declined. In addition, all three subjects showed increases in the per cent of session time spent in alternate condition with successive exposures to the experimental procedure.

The response rate during the alternate condition was low. For the sessions shown in Figure 1, the alternate condition response rate was between one and seven per minute. The cumulative records showed these responses to occur primarily during and immediately after the shock train.

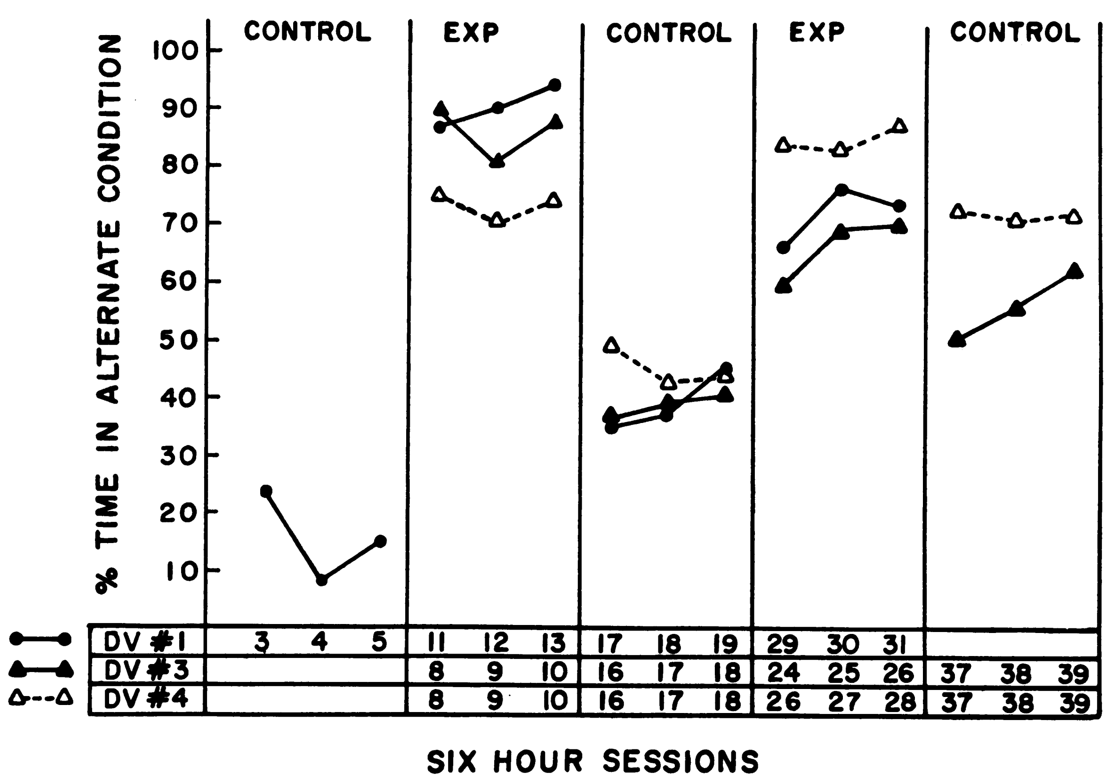


Fig. 1. Per cent of session time in the alternate condition for the last three sessions of each condition for Subjects DV 1, DV 3, and DV 4. During control, shocks occurred twice per minute on a variable schedule whether or not the rat responded. During experimental, a bar press delayed five of the next six shocks, but not the immediately impending shock. Treatments appear in the order administered.

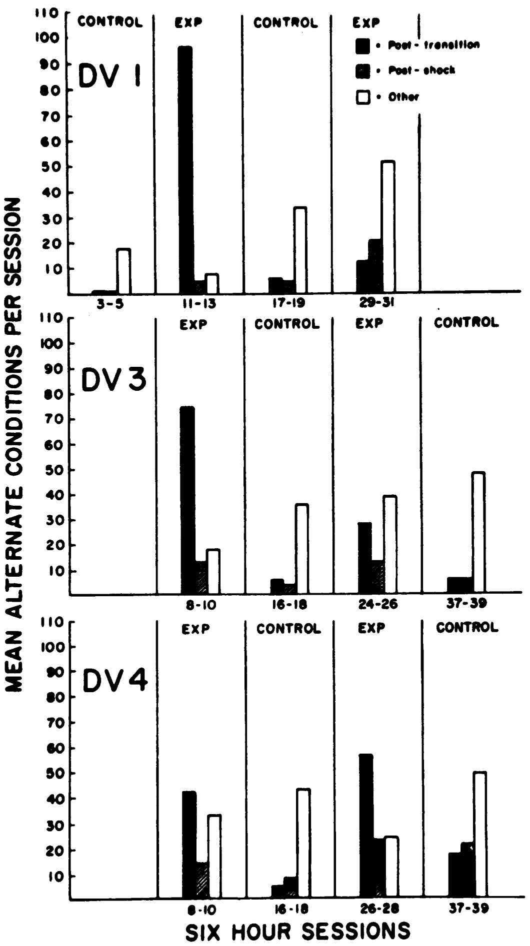


Fig. 2. Mean number of alternate conditions per session produced by posttransition (solid bar), postshock (crosshatched bar), and "other" (open bar) responses during the last three sessions of each treatment for Subjects DV 1, DV 3, and DV 4. Treatments appear in the order administered.

Figure 2 (derived from cumulative records) describes the location of responses in the imposed condition that were effective in producing the alternate condition for three subjects (DV 1, DV 3, and DV 4) in the last three sessions of each treatment. Three different response patterns (posttransition, postshock, and "other") are presented in Figure 2. If, after the alternate condition, no shock had occurred, the response was considered a posttransition response. If, after the prior alternate condition, a single shock had occurred, the response was considered a postshock response. Responses preceded by more than one shock were termed "other" responses. Posttransition responses predominated in the experimental sessions; "other" responses predominated in the control sessions. The large number of alternate conditions in the experimental sessions, compared to the small number in the control sessions, indicates the alternate condition's reinforcing effectiveness.

Stimulus control of responding by the imposed condition was evident in the cumulative records for subjects in the posttransition pattern; the return to the imposed condition determined a high probability of response.

Subject DV 2 did not acquire the response in the initial experimental sessions. For this subject only, sessions were conducted with no shocks in the alternate condition and sessions with only the delayed shocks in the alternate condition. During the course of these sessions, DV 2 acquired the bar-press response, and when subsequently exposed to the experimental treatment, behaved similarly to the other three rats.

## Discussion

Bar pressing was acquired or maintained by a variable-time shock procedure involving no delay to the first postresponse shock and no change in the overall number of shocks.

It is necessary to consider whether responding was maintained by the delayed distribution of shocks in the experimental conditions or by some other aspect of those conditions. One interpretation might be that the rats produced the alternate condition because the pattern of the shocks identified shock periods and shock-free periods. Badia and Culbertson (1972) have shown that rats produce a situation in which shocks are signalled by a tone. According to this analysis, the first shock in the alternate condition may have acted as a signal identifying a shock-free period, the period between the first and second shock, while the second shock identified a high shock-density period, the train of five shocks. Thus, in the experimental treatment, subjects received signalled shock and shock-free periods in the alternate condition and unsignalled periods in the imposed condition. If this analysis is correct, presenting an auditory signal preceding each shock in both the imposed and alternate conditions would clearly identify shock and shock-free periods and eliminate responding. One of the purposes of Experiment II was to test this hypothesis.

An unexpected observation was that, under the control treatment, three of four subjects increased in the per cent of time allocated to the alternate condition, apparently as a function of repeated exposures to the experimental treatment. Powell and Peck (1969) reported a similar finding after bar pressing had been reinforced by shock-intensity reductions. The bar pressing was maintained by response-independent shocks in control procedures when the intensity of shock was not reduced. As in the present experiment, Powell and Peck observed that the behavior tended to be shock-elicited.

To eliminate the discriminative shock and shock-free time analysis and to evaluate the generality of the finding, the experiment was repeated with a number of changes. In Experiment II, we employed a fixed-time shock schedule instead of a variable-time shock schedule, a smaller chamber with a single lever, a constant-current shock source, a 30-sec interval between the last shock in the alternate condition and the re-introduction of the imposed condition, and a signal preceding each shock in both imposed and alternate conditions. These signals ensured that all shock and shock-free periods were clearly identified, and eliminated the possible signalling effects of the first and second shocks in the alternate condition. Finally, the acquisition of bar pressing was studied when some shocks, but not the first two, were delayed.

## EXPERIMENT II

### METHOD

*Subjects*

Eight female albino rats, 90- to 120-days old, of the Sprague-Dawley strain obtained from the Holtzman Company, were experimentally naive and individually caged with free access to food and water.

*Apparatus*

Subjects were tested in one of two chambers 23.3 cm long, 20.4 cm wide, and 20.0 cm high. The 0.15-cm stainless, steel bars in the grid floor were parallel with the 23.3-cm wall and spaced 1.3 cm apart. Clear plastic ceilings were mounted 11.5 cm above the grid floor. A Gerbrands rat lever, 20 g (0.2 N), was mounted 7.1 cm from the side along the 20.4-cm wall and 6.3 cm above the grid floor. A response activated the clicker (85 dB, 10 clicks per second) and illuminated two 6-W bulbs mounted 2.5 cm on either side of the response lever. Continuous 75-dB white noise was on throughout all sessions. Onset of the noise and two houselights (4.8 W), mounted on the back of the 20.4-cm wall, signalled the beginning of the experimental session; offset of the noise and houselights signalled the end of the session. All shocks were preceded by a 4.5-sec Sonalert tone of 2000 Hz (85 dB). Each chamber was enclosed in a wooden acoustical chamber.

A BRS SGS003 constant-current shock source (10% duty cycle) delivered 3.0-mA shock for 0.3 sec to grids, front and rear walls, and response lever. Solid-state switching circuits housed in an adjacent room controlled stimulus events.

*Procedure*

Subjects were tested 6 hr every other day. If the rat failed to respond, it was shocked at regular intervals, once every 30 sec. This FT 30-sec shock schedule was in effect during the imposed condition. During shock and for 5.0 sec following each shock in the imposed condition, responses were ineffective in producing the alternate condition. All other responses in the imposed condition activated a 5-min alternate condition, together with correlated stimuli (clicker and jewelled lights). Responses in the alternate condition were recorded, but had no other effect. At the end of 5 min, the alternate condition (with correlated stimuli) terminated, and the FT 30-sec shock schedule was re-instated. All shocks, both in the imposed and in the alternate condition, were preceded by a 4.5-sec tone. The tone terminated at shock onset.

*Experimental A.* The alternate condition contained the next scheduled shock from the FT 30-sec shock schedule and a train of nine shocks, 5 sec apart beginning 230 sec after the onset of the alternate condition. The time from termination of the shock train to the reinstatement of the imposed condition was 30 sec, during which no shock was delivered.

*Experimental B.* The alternate condition contained the next two scheduled shocks from the FT 30-sec shock schedule and a train of eight shocks, 5 sec apart, beginning 235 sec after the onset of the alternate condition. The time from termination of the shock train to the re-instatement of the imposed condition was 30 sec, during which no shock was delivered.

*Control.* Shocks in the imposed and alternate conditions were delivered on the same FT 30-sec schedule; a response produced the lights and clicker for 5 min.

*Order.* The order for four subjects (SF 1, SF 3, SF 5, and SF 6) was Experimental A, control, Experimental A, and control. Then, three of these subjects (SF 1, SF 3, and SF 5) and three new ones (SF 7, SF 8, and SF 9) were exposed to Experimental B. Subjects had each condition until per cent of time in the alternate condition and pattern of responding appeared stable in the cumulative records for at least three sessions.

## Results

Figure 3 shows per cent of total session time spent in the alternate condition for the last three sessions of each treatment. Subjects SF 1, SF 3, SF 5, and SF 6 spent large percentages of the session in the alternate condition under Experimental A and small percentages under control. In the Experimental B treatment, when responding delayed eight shocks, but not the first two, two of three previously trained rats (SF 1 and SF 3) responded, but none of the three naive rats (SF 7, SF 8, and SF 9) responded. Figure 4 shows the mean number of alternate conditions per session produced by responses classified as posttransition, postshock, and "other" for Subjects SF 1, SF 3, SF 5, and SF 6 under both exposures to Experimental A and control. Posttransition and postshock responses predominated under Experimental A, whereas "other" responses predominated under control. Of the 502 alternate conditions produced during the last three sessions of both exposures to Experimental A for these four subjects, 73.6% were produced by

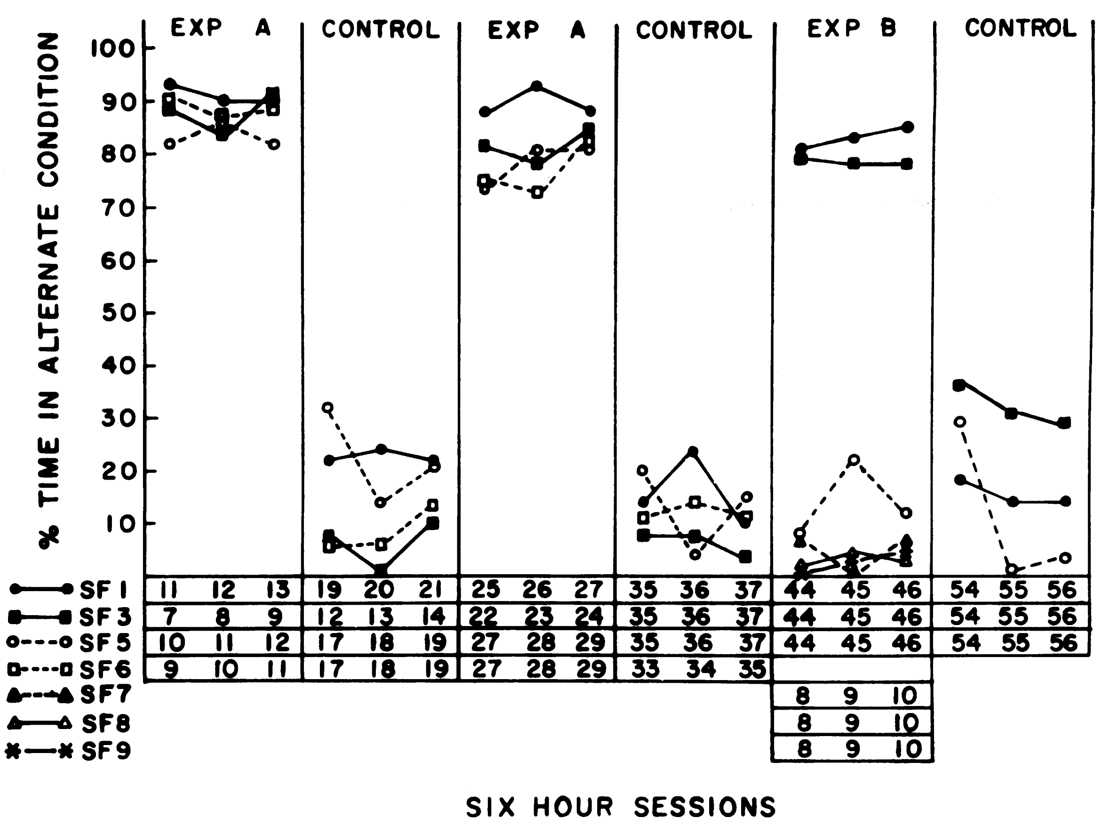


Fig. 3. Per cent of session time in the alternate condition for the last three sessions of each treatment for Subjects SF 1, SF 3, SF 5, SF 6, SF 8, SF 9, and SF 10. During control, shocks occurred twice per minute on a fixed-time schedule whether or not the rat responded. In Experimental A, a bar press delayed nine of the next 10 shocks, but not the immediately impending shock. In Experimental B, a bar press delayed eight of the next 10 shocks, but not the first two shocks after the responses. Treatments appear in the order administered.

either posttransition (35.6%) or postshock (38.0%) responses. In contrast, of the 76 alternate conditions produced in the last three sessions of the first two exposures to control, 88% were produced by "other" responses.

In summary, rats acquired a bar-press response when responding resulted in no change in the delay of the first postresponse shock and no change in the number of shocks. In addition, two animals, with extensive experimental histories, spent large percentages of the session in the alternate condition when responding led to no change in delay to the first two postresponse shocks and no change in the overall shock frequency.

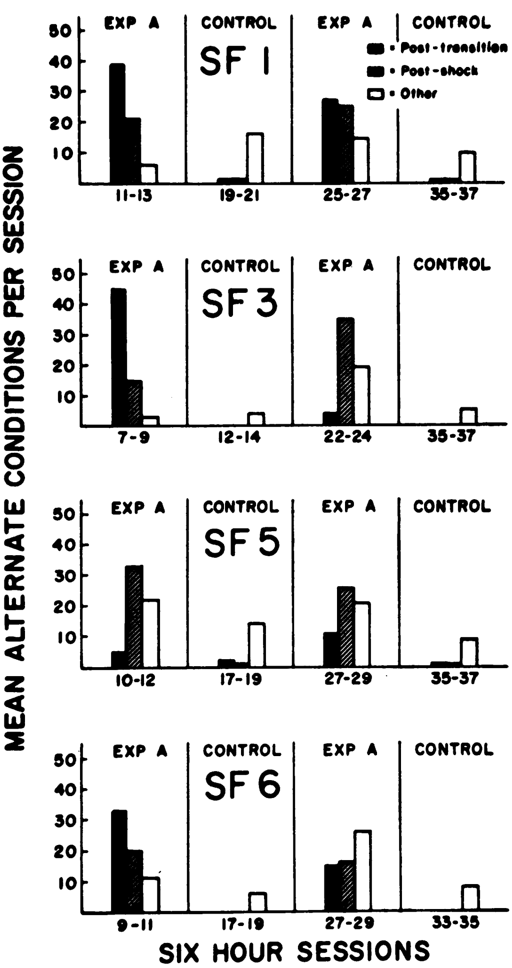


Fig. 4. Mean number of alternate conditions per session produced by posttransition (solid bar), postshock (crosshatched bar), and "other" (open bar) responses during the last three sessions of each treatment for Subjects SF 1, SF 3, SF 5, and SF 6. Treatments appear in the order administered.

## GENERAL DISCUSSION

The primary finding was that rats acquired a bar-press response if some shocks were delayed, even when the first postresponse shock was not delayed and the total number of shocks was not reduced. Previous investigations have shown that increased delay to shock is sufficient to produce avoidance behavior (Gardner and Lewis, 1976; Hineline, 1970). Other investigations have suggested that shock-frequency reduction (Herrnstein and Hineline, 1966; Lambert *et al.,* 1973) may be sufficient. In the present experiments, a response resulted in neither a change in delay to the first shock nor an overall reduction in the number of shocks. The present findings indicate that *neither* an immediate increase in delay to shock *nor* a reduction in overall shock density is necessary for negative reinforcement.

In the discussion of Experiment I, an alternative interpretation of the data was considered. Certain shocks in the alternate condition may have served as signals marking shock periods and shock-free periods. In Experiment II, all shocks throughout each session were preceded by a 4.5-sec tone. The tone ensured that all shock periods were identified, and the tone's absence ensured that all shock-free periods were identified; because responding was acquired even when all shocks were signalled, an interpretation based on discriminable shock and shock-free periods, such as was employed by Badia and Culbertson (1972), is inadequate to explain the present data.

The present data are not explained by the widely accepted two-factor theories of avoidance (Anger, 1963; Rescorla and Solomon, 1967; and Schoenfeld, 1950). For the evaluation of each of the two-factor theories, the implications of these data are about the same; only the Conditioned Aversiveness Temporal Stimuli or CATS (Anger, 1963) will be discussed. Anger postulated that postresponse-time (PRT) stimuli increase in aversiveness monotonically as time elapses; long PRT stimuli are more aversive than short. If, as in free-operant avoidance, a response replaces long PRT with short PRT, the response is immediately reinforced.

The CATS theory cannot explain the present data because the response did not change the first postresponse shock. According to Anger's (1963) curves showing the theoretical relative aversiveness, the relative aversiveness of PRT stimuli immediately after a response was no less in the present experiment than time stimuli before the response. Preresponse stimuli and postresponse stimuli were paired with the same shock. Yet, the response was strengthened.

Several authors (Herrnstein and Hineline, 1966; Sidman, 1962, 1966) have suggested that shock-frequency reduction may explain avoidance; if a response reduces shock frequency or shock density, it is strengthened. Shock-frequency reduction occurs when a response reduces the number of shocks per unit of time. An obstacle limiting the usefulness of the shock-frequency reduction notion is the unspecified length of the "unit of time". For example, in the second experiment of the present report, rats received one shock early and nine later; if the unit of time is relatively short, shock-frequency reduction occurred, if relatively long, no shock-frequency reduction occurred. The overall shock frequency in the present experiment was the same whether or not the rat pressed the bar. In the Gardner and Lewis (1976) study, rats increased shock frequency by a factor of two. The present experiments and others (Gardner and Lewis) are therefore incompatible with the shock-frequency reduction hypothesis stated in terms of overall frequency.

Baum (1973) viewed avoidance schedules as two situations. One situation is in effect before a response, another after a response. If a response increases in probability when it changes one situation to another, the transition is a reinforcer. In the present experiments, the imposed condition was one situation; the alternate condition was another. The fact that responding was reinforced when some shocks, but not all shocks, were delayed implies that the delay to *each* shock influences the value of the situation transition. Delays to all shocks are integrated, and the integrated delays to shocks in the absence of a response *versus* integrated delays to shocks following a response determines the value of the transition.

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