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AN ADJUSTING AVOIDANCE PROCEDURE WITH MULTIPLE AUDITORY AND VISUAL WARNING STIMULI

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Male albino rats were trained on an adjusting avoidance schedule in which each lever press accumulated a given amount of shock-free time. Multiple auditory and visual stimuli were programmed for each discrete temporal distance from the shock in an effort to place the avoidance behavior under the control of the shock proximity. The effects of the stimuli were further examined by presenting part of them and then by removing them altogether. With the combined auditory and visual stimuli, the rat spent most of the time relatively close to the shock and usually started to respond only when the shock was near. With the visual stimuli only, the rat kept the shock at intermediate temporal distances and responded more variably. The behavior with the auditory stimuli alone was quite similar to that produced by the combined stimuli, thus indicating that the auditory stimuli exercised the greater control. When all stimuli were removed, the animal usually kept the shock as far away as the procedure permitted. When only a single pre-shock stimulus was presented, the rat remained quite close to the shock and started to respond predominantly in the pre-shock step.

In a widely used free-operant avoidance procedure (Sidman, 1953), the avoidance response postpones a shock for a fixed period of time. When the subject makes a rapid burst of responses in this situation, all responses after the first have relatively little consequence. Since the first response has already delayed the shock for the maximum (and fixed) time period, the other responses in the burst can add only a small amount of shock-free time. One result of this procedure is that the well-trained subject spaces its responses in time so that each response frequently occurs only a few seconds before the next scheduled shock and thus postpones the shock by a substantial time.

In contrast to the above procedure, an adjusting avoidance schedule (Sidman, 1959, 1962; Baer, 1960) permits the subject to accumulate a constant amount of shock-free time with each response. For example, if one response delays the shock for 10 sec, two responses delay it for 20 sec, three for 30 sec, *etc.* When the subject pauses for 10 sec or more between responses, a timer brings the subject a step closer to the shock. In this manner, the time remaining before the next scheduled shock is a function of both the amount of pausing and of the number of avoidance responses since the last shock. There is a tempting analogy between responding on this procedure and walking up a down-going escalator.

Although the amount of responding determines the temporal distance from the shock, the previous studies of this procedure have not shown that the shock proximity controls the avoidance behavior in a discriminative way. Presumably, after the subject has made a series of responses, paused, responded again, *etc.*, it cannot discriminate its temporal distance from the shock. In terms of the escalator analogy, a blindfolded man who has walked on the escalator for several minutes probably cannot tell how far he is from the bottom. On the other hand, Sidman (1962) observed that the time spent close to and far from the shock is influenced by the presence of a warning stimulus presented just prior to the shock. The present study investigates the effects of multiple warning stimuli programmed to indicate, at each step, the time remaining before the onset of shock. It was anticipated that the stimuli would permit an analysis of the avoidance behavior in terms of the temporal proximity of the shock.

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METHOD

Subjects

Four male albino rats were maintained on a free-feeding and watering schedule in their home cages. Experimental sessions lasted 8 hr, with no nutrients provided. In a situation incorporating multiple visual and auditory warning stimuli, subjects (*S*s) were trained for 41 sessions to achieve a relatively stable state of behavior. Because Rat AL4 was extremely slow in reaching stability, its data is not reported.

Apparatus

A sheet metal experimental box with an 11 by 8 in. grid floor, a height of 11 in. and a removable plexiglass top, was housed in a metal shell to reduce outside light and noise. The floor was comprised of ten 1/4 in. stainless steel rods placed 5/8 in. apart to insure free dropping of feces into a sawdust tray below.

The lever, measuring 1 by 1 by 1/4 in., was inserted through one wall of the box 5/8 in. from the corner and 2 1/2 in. above the grids. The walls, the lever, and the grids were all incorporated in a shock-scrambling circuit which rapidly changed the electrical polarity of each element during the shock. The current was set at approximately 1.0 ma.

The experiment was recorded and programmed automatically by relays, timers, counters, and other associated electro-magnetic equipment. The most critical of these components was an add-subtract stepping relay which was advanced toward the shock step (step 1) by a 10-sec timer and which was driven away from this step by the *S*'s lever-pressing responses.

Procedure

The adjusting avoidance was automatically programmed in the following way. In the absence of lever pressing, a timer moved the stepping relay toward the shock step every 10 sec. When the stepper reached step 1, a .75-sec shock was delivered immediately and was repeated every 5 sec (*i.e.*, the shock-shock interval was 5 sec). When *S* pressed the lever, the stepping relay was advanced away from the shock step, thus accumulating 10 sec of shock-free time with each response (*i.e.*, the minimum response-shock interval was 10 sec). In addition, the response reset the 10-sec timer so that a step back toward the shock could occur only after a 10-sec pause. This differed from Sidman's (1962) procedure, which did not include the timer reset. An upper limit of 10 steps above the shock step was established so that *S* could accumulate a maximum of 100 sec of shock-free time. Responding in the top step reset the timer but did not advance the stepper.

Two classes of multiple exteroceptive warning stimuli were employed in this study. The first was a series of 11 small, green-capped, incandescent lamps mounted 1 3/8 in. above the lever and spaced evenly along the entire length of the wall. Each lamp represented one of the 11 steps. The lamp centered over the lever represented step 1 (shock step) and remained lighted until *S* responded to the shock. The lamp representing step 11 was mounted at the most distant point from the lever and remained lighted as long as *S*'s responding maintained that step.

The second class of stimuli was a series of varying frequency click rates emitted from a small speaker mounted outside the chamber. The highest frequency, 57.7 cps, represented step 1. The frequency decreased in an approximately geometric series through the remaining 10 steps until it reached zero (no stimuli) in step 11. The click rates used for each step were: 57.7, 39.1, 24.7, 16.0, 10.6, 6.5, 4.4, 2.8, 1.5, 0.5, and 0.0 cps.

Shocks and lever-pressing responses were recorded on a Gerbrands cumulative recorder. A strip chart recorder indicated the position of the stepper, giving a moment-to-moment picture of *S*'s temporal distance from the shock. In addition, a bank of magnetic counters recorded the step at which *S*'s avoidance response halted a temporal approach toward the shock and initiated a temporal advance away from the shock. For brevity, the behavior recorded in this way will be referred to as an "initiating response". Because the timer bringing the shock closer was set at 10 sec, the counters were recording the step in which *S* started responding after a pause of 10 sec or more.

Subjects were first trained and stabilized for 41 sessions with both auditory and visual warning stimuli programmed simultaneously for each step. The general plan was then to determine the effects upon the adjusting avoidance performance of the combined auditory and visual stimuli, of each stimulus class alone, and of the removal of both classes of stimuli. This procedure was designed to approximate respectively, maximal, intermediate, and minimal stimulus control. In a final experiment, the stimuli were removed from all except the shock and the pre-shock steps. The order and number of sessions under each condition are indicated in the following figures.

RESULTS

The response rates remained quite stable as long as any class of warning stimuli was present. For example, in 21 sessions the rates for Rat AL1 ranged from 4.8 to 5.6 responses per min, for AL2 from 4.5 to 5.1, and for AL3 from 4.4 to 4.8. Only when both classes of warning stimuli were removed was a change in rate noted. During this time, the rates increased for AL1 to a range of 6.8 to 7.5 responses per min, for AL2 of 5.5 to 6.0, and for AL3 of 5.4 to 5.8. The major changes in performance were observed, not in the response rate or shock frequency, but rather in the distribution of initiating responses.

The following data for Rat AL1 are representative of the other *S*s. In Fig. 1 are sample strip chart recordings selected to show the typical features of the performance under the various stimulus conditions. The pen recorded the position of the stepping relay programming the procedure and thus indicated from moment to moment *S*'s temporal distance from the shock. An upward movement of the pen was produced by lever-pressing, and represented an increase in shock-free time. A downward movement of the pen occurred after 10 sec of no responding and indicated a decrease in shock-free time. When *S* reversed a temporal approach toward the shock by pressing the lever (an initiating response), the point is indicated by a minimum or trough in the record.

The top record illustrates the performance when both the clicks and the lights indicated the temporal proximity of the shock. The animal usually pressed the lever twice before pausing as long as 10 sec, although it also frequently made single presses or bursts of three. The initiating response occurred most often on step 3 (10-20 sec from shock); less frequently on steps 2 and 4. Much the same picture is shown in the third record from the top, illustrating the performance with the auditory warning stimuli alone. With visual stimuli only (second record) the variability is greater, and *S* was less consistent about beginning to respond on any given step. The bottom record (no stimuli were available to indicate the proximity of the shock) shows a quite different performance. Most of the responses occurred on steps 10 and 11. The *S* usually remained as far from the shock as the procedure permitted and only occasionally paused enough to allow the shock to become more imminent.

Figure 2 illustrates the distribution of AL1's initiating responses under the influence of the

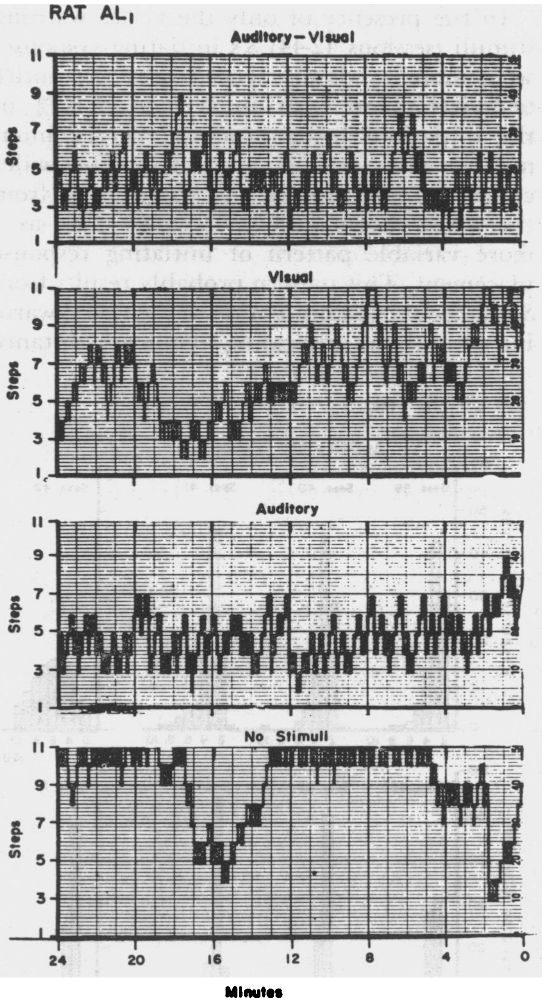

Fig. 1. Strip chart records showing Rat AL1's responding with both classes of multiple warning stimuli, with each class of stimuli alone, and with no warning stimuli. The pen records the position of the stepping relay, hence the temporal proximity of the shock. On these records time runs from right to left.

previously described stimulus conditions. The effects were assessed by calculating the percentage of initiating responses produced in each of the eleven 10-sec steps. These percentages are shown in Fig. 2. In the presence of the combined auditory and visual warning stimuli (sessions 39-41, 45-47, 51-53) AL1's response initiations were closely associated with the minimal temporal proximity of the shock. An average of 44% of the initiating responses occurred in step 3 with approximately 88% falling into the first four steps. The picture here is one of close association with the lower temporal shock distance with very little initiating behavior at maximum safe times.

In the presence of only the visual warning stimuli (sessions 42-44) *S*'s initiating responses were more randomly spaced over the entire temporal range, with an average of 62% of the initiations being produced in the intermediate time periods (steps 4-7). The wider cycles of approaches to and withdrawals from the shock shown in Fig. 1 appear here as a more variable pattern of initiating response placement. This pattern probably results from *S*'s imperfect discrimination of the visual warning stimuli as indicating temporal distance from shock. The fact that the distribution became more peaked from session 42 to session 44 suggests that *S* was acquiring a more precise visual discrimination. In a later experiment, the visual stimuli were programmed for 10 sessions so that *S*s could learn this discrimination more completely. The results on the initiating responses of Rat AL2 are shown in Fig. 3. When the auditory stimuli were removed in Session 63, the curve flattened (although not as much as on the first occasion in Session 42), and the mode shifted from step 3 to step 5. After extensive training (Session 72), the distribution had become more peaked with less variability, but the mode had shifted only to step 4. When the auditory stimuli were again combined with the visual stimuli in Session 73, the mode returned to step 3, the peak was higher, and the variability was reduced. Thus, even after extensive training, the visual stimuli did not achieve quite the same effect as the combined auditory-visual stimuli.

The effects produced by the auditory warning stimuli alone are seen in sessions 48-50 (Fig. 2). Approximately 45% of the responding was initiated in step 3, with an average of 78%

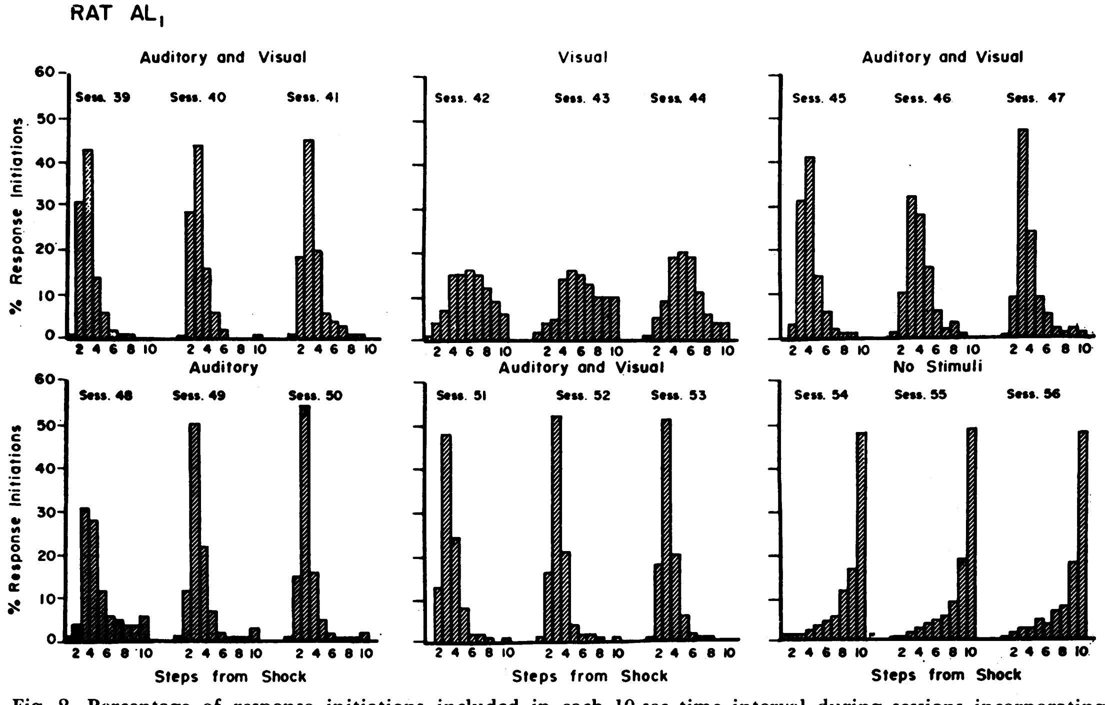

Fig. 2. Percentage of response initiations included in each 10-sec time interval during sessions incorporating both classes of multiple warning stimuli, separate classes of warning stimuli, and no warning stimuli (Rat AL1).

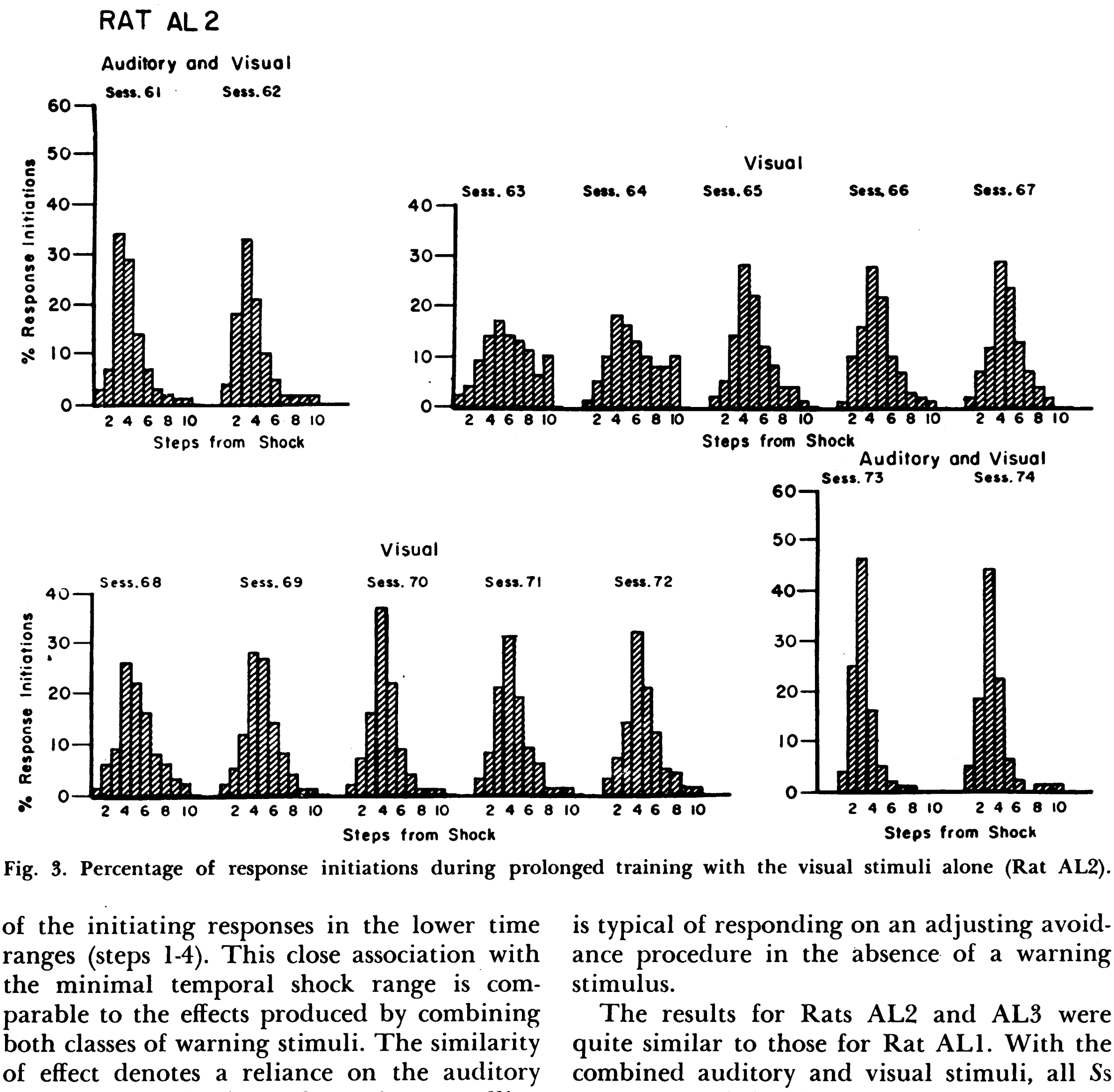

Fig. 3. Percentage of response initiations during prolonged training with the visual stimuli alone (Rat AL2).

of the initiating responses in the lower time ranges (steps 1-4). This close association with the minimal temporal shock range is comparable to the effects produced by combining both classes of warning stimuli. The similarity of effect denotes a reliance on the auditory stimuli as the dominant factor in controlling the initiating responses. This conclusion is further substantiated by the failure of the visual warning stimuli to govern fully the response initiations (note sessions 42-44 in Fig. 2).

The graphs for sessions 54-56 show how the removal of both classes of warning stimuli changed *S*'s initiating responses. Most of *S*'s responding (an average of 76%) began in the maximal temporal range (steps 8-10) and would have extended into a higher range if the procedure had not been limited to 11 steps. This pattern is stable; other rats trained without stimuli for extended periods have responded in the same way. According to Sidman (1962), this nondiscriminant behavior is typical of responding on an adjusting avoidance procedure in the absence of a warning stimulus.

The results for Rats AL2 and AL3 were quite similar to those for Rat AL1. With the combined auditory and visual stimuli, all *S*s spent most of the time close to the shock and usually started responding within the narrow range of steps 2, 3, and 4. When the visual stimuli were removed, little change took place. However, when only the auditory stimuli were removed, *S*s kept the shock at intermediate temporal distances and initiated responding more variably over the entire range of middle steps. When all stimuli were removed, *S*s stayed as far from the shock as possible and responded most frequently in the top step. The order of studying the auditory stimuli and the visual stimuli alone was reversed for AL3, and there was no indication that order was an important variable.

In a final experiment, the combined auditory and visual stimuli were programmed only

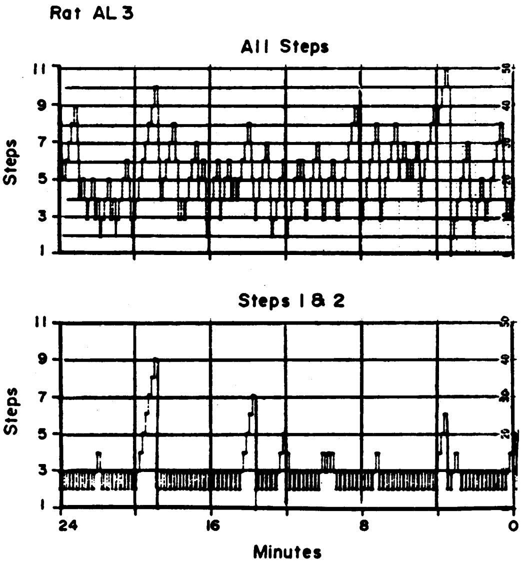

Fig. 4. Strip chart records showing the performance of Rat AL3 when auditory and visual warning stimuli are present on all steps (top record) and on steps 1 and 2 only (bottom record). After a shock (indicated by the pen touching step 1), the rat typically responded in a rapid burst.

for the shock step and the pre-shock step (steps 1 and 2). The procedure for presenting the stimuli was similar to the classical avoidance situation since a warning stimulus precedes the shock by 10 sec. However, because of the adjusting avoidance procedure, the length of the "inter-trial interval" (the time between warning stimuli) could be controlled by the animal. Two strip chart records showing Rat AL3's performance with stimuli on all steps (top) and on steps 1 and 2 (bottom) are shown in Fig. 4. The top record illustrates the wide cycles of approach to and withdrawal from the shock. The bottom record shows the sharp reduction in the width of the cycles after the stimuli were removed from steps 3 to 11. The animal typically waited for the warning stimulus and then made a single response which terminated it. Thus, Rat AL3 usually provided itself with a 10-sec inter-trial interval. The other *S*s showed slightly greater variability in the length of the burst, but otherwise the effects were the same. A similar picture is shown in Fig. 5 in terms of the initiating response. On the first session after the stimuli were removed from steps 3-11 (Session 82), 77% of the initiating responses occurred on step 2. By Session 99, the percentage had risen to 92. The fact that the rat usually started its avoidance responding in the pre-shock step is consistent with Sidman's (1962) finding that a pre-shock warning stimulus caused the animal to spend more time in the close temporal vicinity of the shock.

DISCUSSION

From the experiments with multiple warning stimuli, the following conclusions can be drawn: 1) With the maximal stimulus control used in this experiment (both classes of stimuli), *S*'s responding was closely associated with minimal temporal distances from shock. A similar effect resulted from the auditory stimuli alone. 2) With intermediate stimulus control (in the presence of only the visual warning stimuli), *S*'s response initiations occurred at intermediate temporal distances from shock. 3) With minimal stimulus control (in the absence of both classes of multiple warning stimuli), *S*'s response initiations occurred at maximal temporal distances from shock. 4) Of the two classes of warning stimuli employed, the auditory stimuli were the more effective in governing the response initiations. In the absence of more extensive data, however, this conclusion must be limited to the specific auditory and visual stimuli used in this study. 5) In the presence of both or either of the two classes of warning stimuli, a cyclic effect was noted, in that *S* would approach and partially withdraw from the shock, but would rarely respond in such a manner as to impose the maximum temporal distance between itself and the shock. 6) In

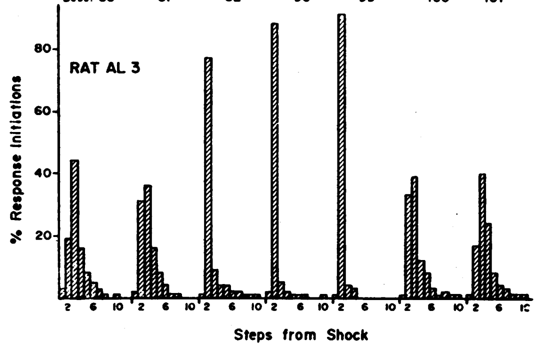

Fig. 5. Percentage of response initiations when warning stimuli were used for all steps (Sessions 80-81 and 100-101) and for steps 1 and 2 (Sessions 82, 90, and 99). Sessions 82, 90, and 99 illustrate the performance of Rat AL3 at the beginning, middle, and end of training with stimuli on steps 1 and 2.

the absence of all warning stimuli, the cyclic effect was not so prominent, and *S*'s responding usually kept the shock as far away as permitted by the procedure.

The various stimulus conditions studied in this experiment can also be interpreted in terms of stimulus generalization. Since the rat probably cannot precisely discriminate each of the 11 stimuli associated with the 11 temporal steps from the shock, some stimulus generalization must occur from step to step. Minimal generalization (the combined auditory and visual stimuli) permits the rat to approach the shock closely and to respond rather precisely over a narrow distribution of steps. With intermediate generalization (the visual stimuli) the shock is approached less closely, and the initiating responses are scattered more widely among the middle range of steps. With maximum stimulus generalization (no stimuli) the rat usually imposes the maximum temporal distance between itself and the shock and responds in the top steps.

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