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SECOND-ORDER OPTIONAL AVOIDANCE AS A FUNCTION OF FIXED-RATIO REQUIREMENTS[1]

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Two rhesus monkeys responded on a fixed-ratio schedule in Stimulus 1 (blue light) to avoid the onset of Stimulus 2 (green light). Failure to avoid Stimulus 2 required a second fixed-ratio performance to avoid Stimulus 3 (red light) in the presence of which unavoidable shock occurred. Relative frequencies of avoidance performance in the blue light and in the green light were inversely related to the ratio requirement under each stimulus condition. Both differential response-cost and avoidance-failure probability factors were related to the observed changes.

Several recent studies of second-order reinforcement schedules (Zimmerman, 1963; Findley and Brady, 1965; Kelleher, 1966; Thomas and Stubbs, 1967; Davison, 1969) have focused upon the analysis of positively maintained performance baselines. Second-order effects on aversive schedules of reinforcement have received little or no direct experimental attention, though reports by Field and Boren (1963) and Findley, Schuster, and Zimmerman (1966) have clearly established the importance of such second-order control in the maintenance of avoidance behavior. Field and Boren (1963), for example, demonstrated discriminative control of an adjusting avoidance performance in rats by stimuli providing information about temporal proximity to shock. Though the animals never effectively escaped from the progression of stimuli preceding shock, they did maintain a level of responding that kept them several discrete steps from the primary aversive event.

The present report describes a more direct and extensive analysis of the role of second-order conditioned aversive stimuli in the maintenance and control of avoidance behavior. Specifically, this experiment analyzes a discriminated avoidance situation characterized by (1) the exclusive use of conditioned aversive stimuli as the immediate consequence for not responding, (2) a provision for avoidance in one of two alternative conditions in successive proximity to the ultimate aversive event, and (3) the use of discrete fixed ratios as the performance required for successful avoidance.

METHOD

Subjects and Apparatus

Two male rhesus monkeys, 3 yr old at the start of the experiment, and each weighing approximately 5 kg, were maintained in primate restraining chairs (Mason, 1958) and enclosed in isolation booths (Foringer) throughout the course of the experiment. A white noise (70 dB re 0.002 dyne/cm^2) masked apparatus sound and other extraneous stimuli.

In conducting the present research, the investigators adhered to the "Guide for Laboratory Animal Facilities and Care", as promulgated by the Committee on Revision of the Guide for Laboratory Animal Facilities and Care of the Institute of Laboratory Animal Resources, National Academy of Sciences—National Research Council.

A Lindsley response-lever mechanism mounted on the chair 15.25 in. (6 cm) in front of the monkey just above waist level, provided for the recorded operant response. A stimulus array of eight colored bulbs (two each of red, blue, green, and white) was mounted inside an aluminum box approximately 3 ft (15 cm) from the monkey's face at eye level. The side of the box facing the monkey was covered with milk-white glass that diffused the light and presented a uniformly colored stimulus patch measuring 100 cm^2. Shock of approximately

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180 mA for 1 msec was delivered through the neck plate and seat of the restraining chair using a constant current source as described by Swinnen, Brady, and Powell (1969). All scheduling and recording of the experiment was accomplished automatically and remotely by means of a system of relays, timers, counters, cumulative recorders and associated switching circuitry.

Procedure

Performance on the Lindsley manipulandum was established initially for both monkeys on a schedule of positive reinforcement that required the emission of 30 responses within a 30-sec interval (FR 30, LH 30) to obtain food (P. J. Noyes, 1-g monkey pellets). Exposure to this contingency was arranged in the presence of a green light using a discrete trial procedure with a 90-sec time base. Upon completion of the ratio within 30 sec, the green light was extinguished, food pellets were delivered, and a timeout interval with no scheduled contingencies completed the remainder of the 90-sec trial. Failure to meet the ratio requirement in 30 sec produced only a 60-sec timeout terminated by the reappearance of the green light and the beginning of a new 90-sec trial. Performance was maintained on this schedule for three 100-trial sessions, at which time both monkeys were obtaining 95% of the food pellets available.

Over the next 10 daily sessions, the probability of food reinforcement following successful completion of the FR 30, LH 30 was progressively reduced through successive steps (1.0, 0.6, 0.3, 0.1) to zero while concurrently introducing the aversive control procedure. By the ninth session for example, positive reinforcement probability was reduced to 0.1 and all failures to complete the ratio within 30 sec in the presence of the green light resulted in a change of the light stimulus from green to red for a period of 3 sec, during which three brief (1-msec) shocks were delivered. No shocks were ever delivered in green, but only in red as a delayed consequence for not responding in green. By the eleventh session, with both monkeys receiving only 25 to 30% of the possible number of shocks, positive reinforcement was discontinued and session length was set at 2 hr (approximately 80 discrete trials). Beginning with Session 14, a blue stimulus light was scheduled during the first 30 sec of each 90-sec trial. Thirty responses during this first 30-sec period extinguished the blue light, terminated the trial, and produced a timeout for the remainder of the 90-sec trial interval. Failure to emit 30 responses in the presence of the blue light produced the green light with all the ensuing requirements and consequences previously described. If the requirement of 30 responses within the 30-sec green light period was satisfied, a timeout period for the remainder of the trial was scheduled. If 30 responses were not emitted in the presence of either the blue or the green stimulus, the 3-sec red light reappeared with unavoidable shocks. The 30 avoidance responses had to be completed in either the blue or the green stimulus because the requirement could not be met cumulatively over the 60-sec blue-green interval.

During Session 16, the baseline avoidance performance was integrated into the 24-hr recycling program illustrated diagrammatically in Fig. 1. Beginning at 10 a.m. each morning and after housekeeping requirements were completed (*e.g.*, waste removal, feeder refill, apparatus check), a recycling 8-min fixed-interval schedule with a limited hold of 1 min (FI 8-min, LH 1-min) for food reinforcement was scheduled for 1 hr in the presence of a white stimulus light. The first lever response occurring between the eighth and ninth minute after delivery of the previous reinforcement produced five food pellets. At 11 a.m., the second-order optional avoidance procedure was introduced for 2 hr followed by a 3-hr "rest" period with no scheduled contingencies. This 6-hr cycle repeated four times during each 24-hr period.

After performance on the baseline second-order avoidance schedule (FR 30, Blue; FR 30, Green) had stabilized, the ratio requirement in each stimulus was systematically manipulated. Over 153 daily sessions, the ratio requirement in the blue (distal) stimulus light was maintained at 30 while the requirement in the green (proximal) stimulus changed in the following order: FR 60 (50 sessions); FR 90 (35 sessions); FR 120 (40 sessions); FR 15 (28 sessions). During the next 76 daily sessions, the ratio requirement in the proximal stimulus light was maintained at 30 while the requirement in the distal stimulus changed in the following order: FR 15 (36 sessions); FR 5 (15 sessions); and FR 60 (25 sessions).

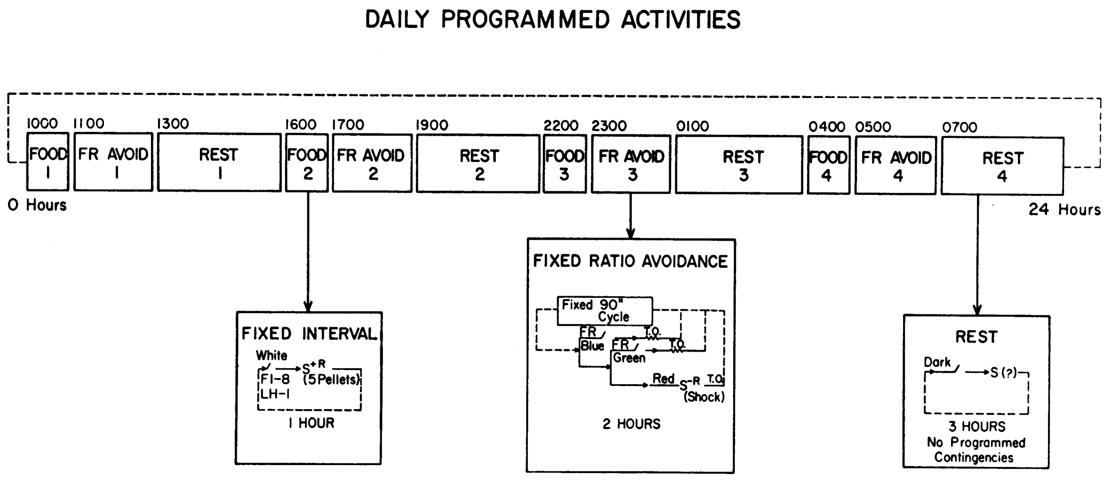

Fig. 1. Diagrammatic representation of daily scheduled activities in recycling 24-hour sequences. The insert labelled FIXED INTERVAL indicates the stimulus and scheduled dependencies during the four, hour long, food periods. Similarly, the inserts labelled FIXED RATIO AVOIDANCE and REST respectively detail the environmental conditions during the eight hours of avoidance and the twelve hours of rest.

RESULTS

Figure 2 illustrates the essential features of the stable baseline performance for each monkey established before systematic variation of the avoidance ratio requirements. Typical cumulative records of fixed-interval food (FI 8-min, LH 1-min) and fixed-ratio avoidance (FR 30, Blue; FR 30, Green) performances are shown for each animal during continuous 2-hr segments of the 24-hr experimental session. The characteristic temporal patterning of responses during the fixed-interval food segments of the schedule emerged early in training and was maintained consistently by both animals throughout the experiments with no changes as a function of the fixed-ratio requirement manipulation. Following the FI 60-min segment shown in Fig. 2, the cumulative records detail the optional avoidance performance of each animal on a trial-by-trial basis during the first hour of the 2-hr avoidance segment. The ratio satisfying the requirement of each trial is followed by a pause in responding of varying length representing principally the timeout produced by termination of the trial. The two event pens at the base of each record mark the occurrence of completed ratios in either the blue or green stimulus and reflect the predominance of "green" ratios for Monkey 1 and a more equal occurrence of "blue" and "green" ratios for Monkey 2. Failures to satisfy the optional avoidance requirement, and hence the associated "red-shock" condition are indicated by the diagonal deflection of the cumulative recording pen for each animal. As shown in Fig. 2, failures to avoid shock by not completing the ratio requirements during either the distal or proximal stimulus occurred only infrequently.

Results of the first experiment in which the fixed-ratio requirement in the proximal stimulus was varied from FR 15 to FR 120, while the ratio in the distal one held constant at 30 are presented in Fig. 3. Shown for each animal are mean values derived from the last five sessions under each condition for the number of avoidance failures per session ("misses"), the number of completions in each color per session, and the per cent completions per opportunity in the proximal stimulus. During each daily session there were 320 avoidance trials. Inspection of total misses in Fig. 3 shows overall avoidance accuracy to be generally high for both animals. Avoidance failure as a per cent of total trials is on the order of 10% even at FR 120 in the proximal stimulus. The highest overall avoidance accuracy is found at FR 15. The distribution of successful avoidances between the two stimulus conditions is revealed

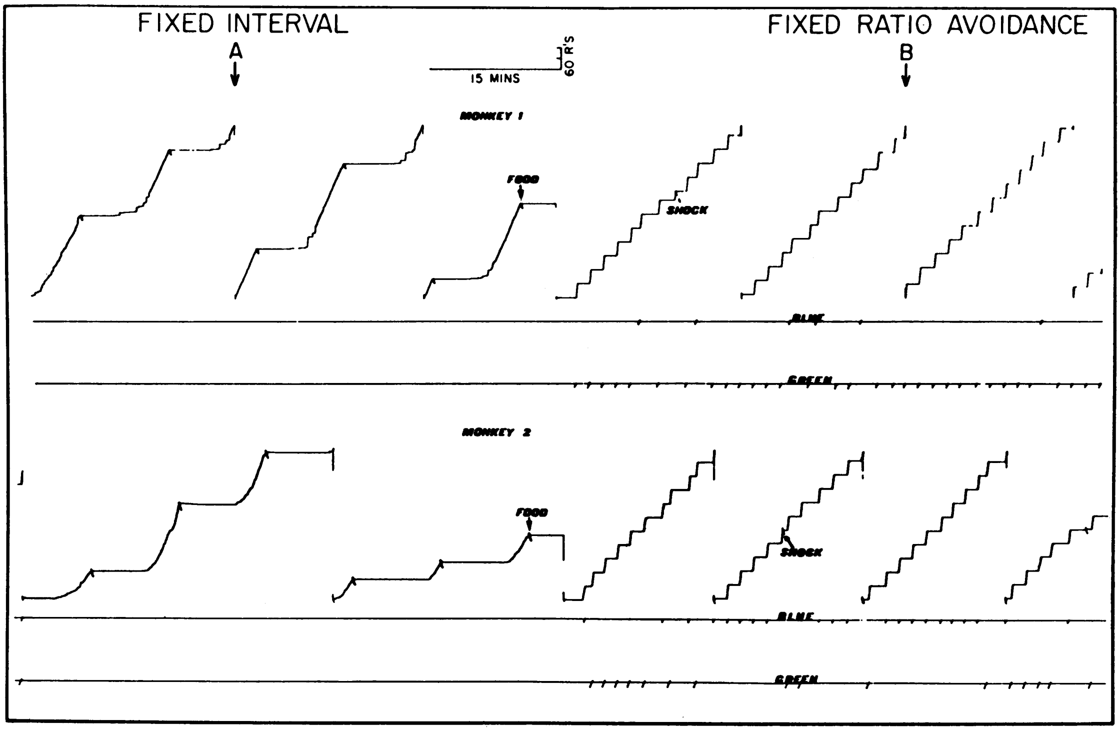

Fig. 2. Sample cumulative response curves illustrating stable baseline performances for Monkeys 1 and 2 during one-hour fixed interval (A) and fixed ratio (B) segments. The data presented are for the condition where the ratio requirement was equal in the proximal (GREEN) and distal (BLUE) conditions.

by examination of total completions in each color. At FR 30, both animals showed a bias or high completion rate in the proximal stimulus. Increases in the fixed-ratio requirement in green above FR 30 resulted in reversal of this bias with a predominance of completions in the distal component, particularly at FR 90 and FR 120. The lower section of Fig. 3 shows per cent completions per opportunity in green and reveals the avoidance accuracy in the proximal stimulus on those trials in which completions were not made in the distal one. As the fixed-ratio requirement in the proximal stimulus was increased, avoidance failures in that component increased substantially if a successful completion had not been made in the distal stimulus. Even though the overall avoidance performance was high throughout the manipulation of ratio size in the proximal stimulus, at the higher fixed-ratio values (90, 120), failure to complete in the distal one substantially increased the probability of shock. At FR 120, for example, overall avoidance accuracy on the order of 90% was totally accounted for by performance in the distal stimulus, since no completions occurred in the presence of the proximal condition.

In the second experiment, the requirement in the proximal stimulus was held constant at FR 30, while that in the distal one changed from FR 15 to FR 5 and then to FR 60. Results of this experiment, together with data from the FR 30, FR 30 condition, are shown in Fig. 4. The mean misses per session reflect a high stable level of performance accuracy under each of the varying fixed-ratio requirements in blue by comparison with the FR 30, FR 30 condition. Examination of per cent completions per opportunity in the proximal stimulus shows that probability of avoidance in that condition was also invariant and virtually independent of relative frequency of completions in the distal stimulus. For Monkey 1, only FR 5 in blue resulted in a greater absolute number of blue completions over green, while in the case of Monkey 2, the number of blue completions was higher than green completions at both FR 5 and FR 15 in blue.

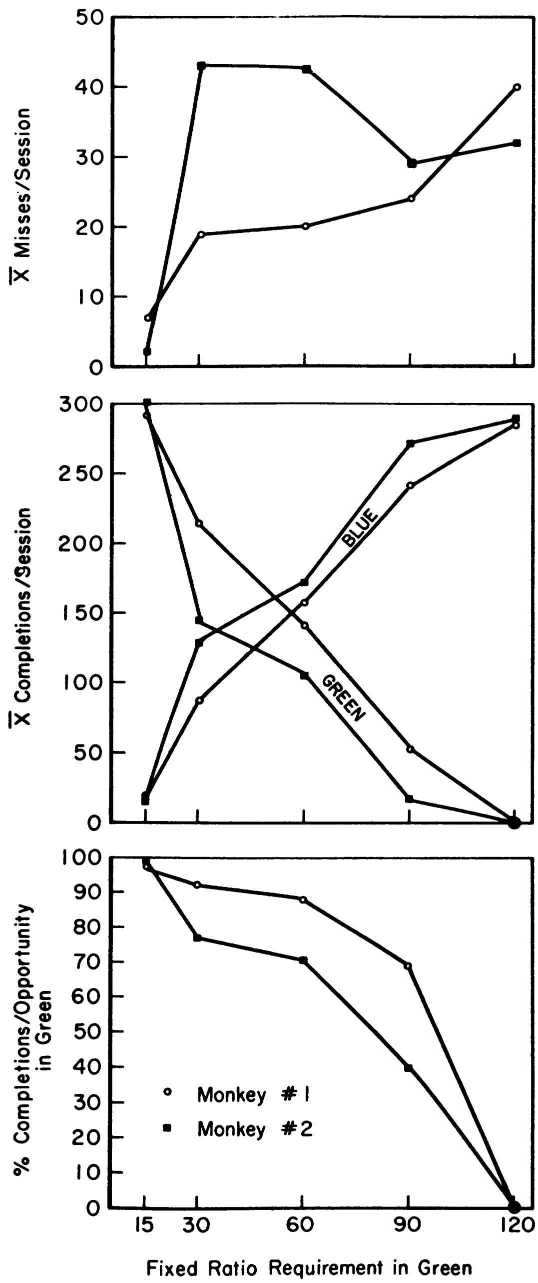

Fig. 3. The results of manipulating fixed ratio requirement in the proximal (GREEN) stimulus. The ratio size in the distal (BLUE) stimulus remained constant at FR 30 throughout the experiment. Each data point represents the mean of the last five sessions at each value of the ratio in GREEN.

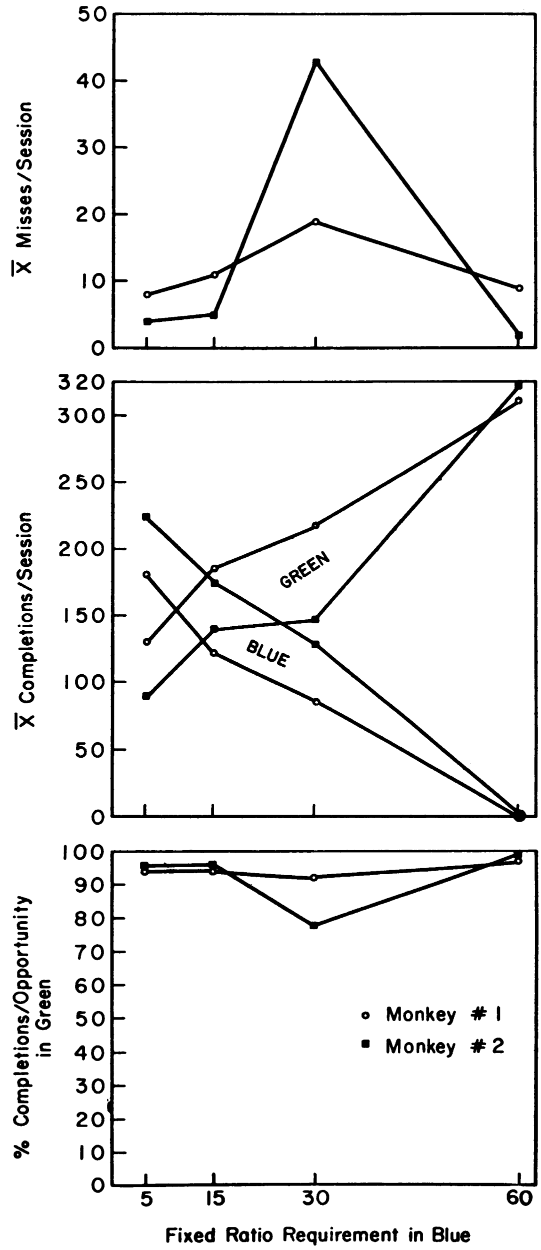

Fig. 4. The result of manipulating fixed ratio requirement in the distal (BLUE) stimulus. Throughout the experiment the ratio requirement in the proximal (GREEN) stimulus remained constant at FR 30. Each data point represents the mean of the last five sessions at each value of the ratio in BLUE. The data plotted for the ratio value FR 30 are based on the results from the first experiment.

DISCUSSION

The results of the two experiments show clearly that the probability of a successful avoidance performance in each of two stimulus conditions differing in temporal proximity to shock is a function of relative response requirement in each condition. In the first experiment, both monkeys completed the avoidance tasks almost exclusively in the stimulus closest to the shock when the response requirement in that stimulus was lower than in the distal one. When the response requirements in both conditions were equal, the monkeys continued to show a higher frequency of avoidance completions in the proximal stimulus. As the ratio requirement in green was increased, however, the frequency of avoidance completions in the distal (blue) stimulus condition increased. This change in performance was not due to the monkeys' inability at the higher ratio values to fulfill the response requirement in the time alloted. The monkeys either initiated a ratio run and completed the required number of responses, or they allowed the time to elapse without making a response. One factor contributing to this shift, however, would seem to be the decrease in avoidance completions per opportunity in the proximal (green) stimulus as the ratio requirement in that condition was increased. Correlation of the green stimulus with an increasing probability of avoidance failure as the ratio increased could account, at least in part, for strengthening of the avoidance performance in the distal stimulus which prevented the occurrence of the proximal stimulus condition.

A second factor that must be considered in accounting for the results of the first experiment is response cost. Anytime the fixed-ratio requirement in the proximal stimulus exceeded that in the distal one, a net "savings" was possible in the number of responses necessary to avoid shock successfully by responding in the distal stimulus condition. When the fixed-ratio requirement in green was FR 60, for example, only half as many responses were required in the distal component to avoid the aversive contingency. When the ratio in green was raised to 120, four times as many responses were required to avoid in that condition as compared to the distal one. Thus, both differential response cost and a higher probability of avoidance failure could have combined to produce a degree of aversiveness in the proximal stimulus condition that increased the frequency of avoidance completions in the distal condition.

In the second experiment, both monkeys showed a systematic decrease in avoidance completions in the distal (blue) stimulus as the ratio requirement in that condition increased. Significantly however, completions per opportunity in the proximal stimulus remained constant across virtually all values of the blue ratio, a finding in marked contrast to the results of the first experiment. Under these conditions, variations in the performance requirement during the distal stimulus had little effect upon the overall probability of avoidance completions.

The results of the second experiment do, however, confirm the role of a response-cost factor in the distribution of avoidance completions between the blue and green stimulus condition. Variations in the frequency of proximal and distal avoidance completions were functionally related to changes in the ratio requirement during the distal (blue) stimulus. When only five responses were required to avoid in the blue, as compared to 30 in the proximal stimulus, both monkeys showed a strong preference for avoidance completion performances in the distal stimulus condition, providing a net "savings" of 25 responses. Conversely, when the ratio requirement in the distal stimulus was increased to 60, with the requirement in the proximal held constant at FR 30, avoidance completions shifted to the proximal stimulus condition exclusively, providing a net "savings" of 30 responses for both animals with no change in the number of overall avoidance failures or misses.

The final conclusion derived from a comparison of the results obtained in the first and second experiments would suggest a differential sensitivity of the distal and proximal avoidance conditions to changes in the ratio requirements. Addition of identical increments (30 responses) to the avoidance requirement in the distal and proximal stimulus produced a much larger shift away from the distal condition than from the proximal condition. Similar differential preference shifts have been reported by Findley (1962) in experiments with sequential behavior chains maintained by positive reinforcement. Indeed, the present results clearly establish the feasibility of maintaining such higher order behavior sequences based solely upon procedurally acquired aversiveness by remote stimuli (*e.g.*, the blue and green light) never directly paired with shocks.

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