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REINFORCEMENT OF MEDIATING BEHAVIOR ON A SPACED-RESPONDING SCHEDULE

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This paper describes a procedure for gaining experimental control over mediating behavior on a spaced-responding schedule of food reinforcement. Three rats, food-deprived, were trained on a DRL 16 sec schedule of food reinforcement. Then, a concurrent schedule of food reinforcement was introduced on a second (mediating) lever, such that the first response to occur on the mediating lever, after the DRL interval had timed out, was reinforced with food, as was the next response to occur on the DRL lever. Reinforcement via the mediating lever became a discriminative stimulus for a food-reinforcement opportunity on the DRL lever. Next, food reinforcement for the mediating behavior was replaced by a conditioned reinforcer consisting of onset of a buzzer signaling timing-out of the DRL interval. Under these conditions, chaining of behavior on the two levers was strong, and timing on the DRL lever was more accurate than under ordinary DRL conditions. As the DRL requirement was lengthened from 16 sec to 24 sec to 60 sec, mediating behavior weakened slightly. When the inter-response requirement for food reinforcement on the DRL lever was made shorter than the inter-response requirement for conditioned reinforcement on the mediating lever, the mediating behavior extinguished. Performance in the experiment was analyzed into a four-component chain, and the factors contributing to the maintenance, and later extinction, of mediating behavior are discussed.

On a spaced-responding schedule, anything the animal does which has the effect of introducing a sufficient temporal delay between timing responses can be expected to be adventitiously reinforced; a superstitious chain will develop. Sidman (1960) has suggested that the way to study the role of overt mediating responses in timing behavior is to render the mediating behavior an explicit, reinforced component of the experimental situation. Thus, *what* behavior comes to serve the mediating function is not left to chance and adventitious reinforcement. By rendering the mediating behavior an explicit component of the schedule, it becomes possible to observe and record the behavior, and to manipulate it experimentally.

This paper describes a procedure for gaining experimental control over mediating behavior on a DRL schedule, and reports data for two experiments.

EXPERIMENT 1: DRL 16 SEC

Method

Three naive, adult, male albino rats, maintained at 80% of free-feeding weight, were trained to press one of two levers, the DRL lever, on a DRL 16 sec schedule of food reinforcement. The reinforcer was diluted condensed milk enriched with vitamins. A second lever present in the experimental apparatus, the mediating lever, was inoperative in this stage of the experiment; presses were recorded but were not reinforced.

All animals were kept on the DRL schedule for 45 sessions of 150 reinforcements each, by which time every animal showed typical DRL behavior (Sidman, 1956). Responding was at a low, more or less steady rate, and a relative preponderance of inter-response-times (IRT's)

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was in the vicinity of the DRL requirement of 16 sec.

Following the 45th session on DRL 16, a concurrent schedule of reinforcement was introduced on the mediating lever. The mediating lever was connected to the reinforcement magazine in such a way that when the DRL 16 had "timed out" a single response on the mediating lever was reinforced with food. Mediating-lever responses did not start a new DRL timing interval, however. Only DRL-lever responses, whenever they occurred, reset the DRL interval. Thus, the time between reinforcement opportunities on both levers depended on the temporal pattern of DRL-lever responding.

Precautions were taken to insure that food reinforcement was obtainable only via a chained sequence of behavior; when the DRL interval timed out, the first response on the mediating lever was reinforced, and the next response on the DRL lever was also reinforced. Then a new DRL timing interval began. If the first response following timing-out of the DRL occurred on the DRL lever, it did nothing more than reset the DRL interval; it was not reinforced. In this way, reinforcement for a mediating-lever response was established as a discriminative stimulus setting the occasion for reinforcement on the DRL lever.

This procedure was continued for just three sessions of 150 food reinforcements each, by which time all animals were emitting the required chain of behavior. Then the chaining requirement was removed. Now reinforcement was available by three alternative routes: (1) As in the first stage of the experiment, DRL-lever responses, if spaced 16 sec apart, were food-reinforced. (2) As in the required-chain procedure, mediating lever-DRL lever response sequences were reinforced with food for both members of the chain. (3) Responding exclusively on the mediating lever resulted in food reinforcement according to a simple FI 16 sec schedule.

Only by route (2) could the maximal rate of reinforcement occur. Thus, the procedure favored mediating lever-DRL lever sequences. Moreover, and most important, a mediating-lever reinforcement provided a reliable cue for a reinforcement opportunity on the DRL lever. It is worth reiterating that in the "optional chain" procedure here described, behavior on the mediating lever could continue throughout the DRL interval without resetting the DRL timing interval, and thus without affecting the time between food-reinforcement opportunities on either lever.

The optional chain procedure, with each member of the chain reinforced with food, continued for 54 sessions. Then, a final modification of the procedure was introduced. Now, animals were no longer reinforced with food for mediating-lever responses. Instead, when the DRL interval timed out, corresponding to the passage of 16 sec since the last DRL-lever response, the very next response, if it occurred on the mediating lever, turned on a buzzer. The buzzer then remained on until a food-reinforced response was made on the DRL lever. In this and all succeeding experimental manipulations, behavior on the mediating lever was reinforced only by the onset of the discriminative auditory stimulus (the buzzer) setting the occasion for a reliable food-reinforcement opportunity on the DRL lever.

The final stage of the experiment continued for 10 sessions. As previously, mediating-lever responses did not reset the DRL timer. Thus, the schedule of reinforcement on the mediating lever amounted to FI 16 sec for a conditioned reinforcer (the buzzer) provided that no "premature" responses occurred on the DRL lever while the DRL interval was timing.

The complicated experimental manipulations just described constitute a procedure for shaping explicit mediating behavior on a spaced-responding schedule. In the terminal stage, the mediating behavior was maintained exclusively by its ability to produce the cue for successful DRL responding.

Results

The first two cumulative curves of Fig. 1 show the terminal performance of Rat No. 3 on the mediating lever. The curve labeled 16F shows responding when mediating-lever responses were still reinforced with food. The curve labeled 16B shows responding when mediating-lever responses were reinforced only by buzzer onset. Reinforcements, whether food or buzzer-onset, are indicated by oblique pen marks.

These two curves demonstrate that sequential chaining of behavior on the two levers occurred regularly. The regularity of spacing

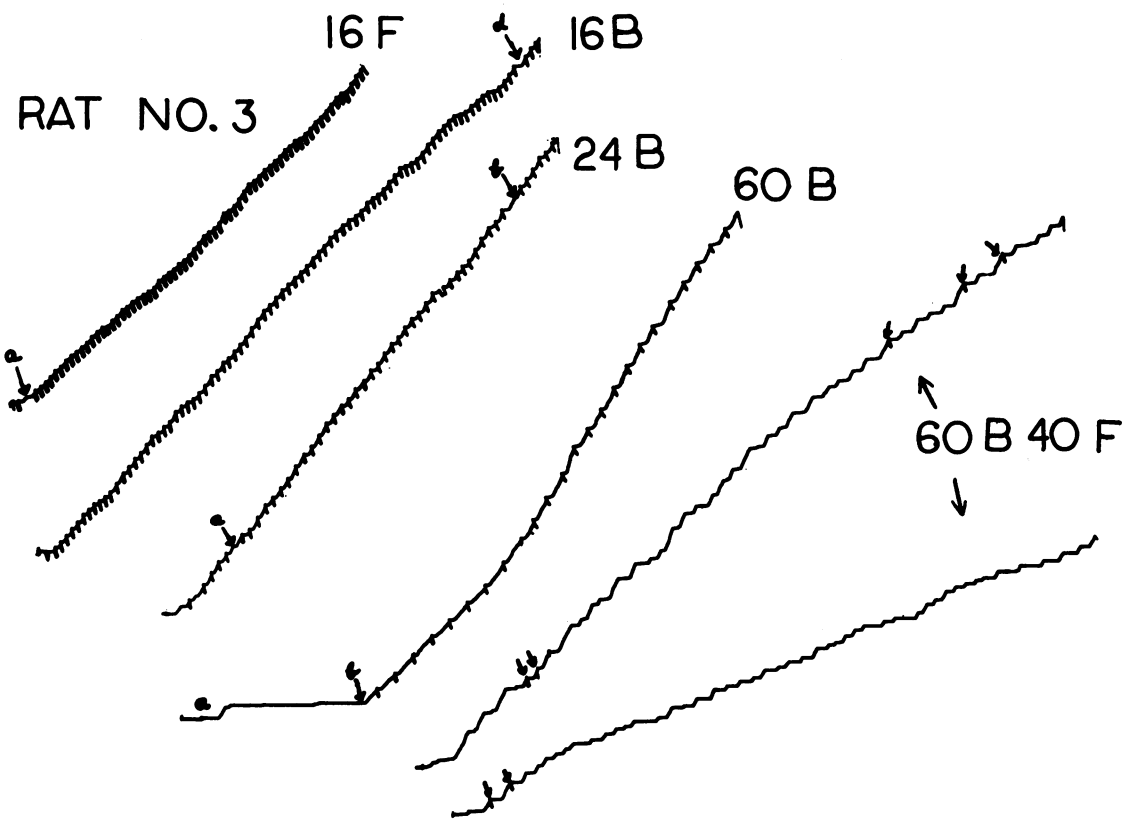

Fig. 1. Rat No. 3: Cumulative response records of responding on the mediating lever.

of mediating-lever reinforcements, and the steady rate of responding on the mediating lever, are evidence that the animal's behavior consisted almost entirely of cyclic chains: responding on the mediating lever until reinforcement, followed by a single (reinforced) response on the DRL lever, followed by a switch back to the mediating lever, and so on through the chain.

At the points labeled *a* and *d* in Curves 16F and 16B appear two of the rare instances when chaining on the two levers failed to be completed. DRL reinforcements were obtained at those points without prior mediating-lever reinforcement.

A feature of the mediating-lever performance that is more evident in the third and fourth curves of Fig. 1 (Curves 24B and 60B), but appears, also, in the first two curves, is the "scalloped" rate characteristic of fixed-interval responding. This is further evidence that the effective schedule of reinforcement on the mediating-lever was a fixed-interval for buzzer-onset, and that no premature DRL responses were occurring to derange the FI 16 sec schedule.

Performances of the other two animals were similar, with all three animals showing the fixed-interval-like mediating behavior on the mediating lever. However, two differences between the performances of the rats were seen: (1) Rats No. 1 and No. 2 showed slightly more failures to complete the chain when buzzer was the reinforcer than when food was the reinforcer for mediating-lever responses. Rat No. 3 showed fewer failures of chaining under buzzer reinforcement. (2) Rats No. 1 and No. 2 showed little or no increase in mediating-lever response rate when buzzer was substituted for food. In contrast, Rat No. 3's response rate increased noticeably under buzzer reinforcement. (Eating time was not subtracted from the response records, and probably accounts for the increased rate of mediating-lever responding when such responding was no longer food-reinforced.)

Figure 2 presents the distribution of inter-response-times on the DRL lever. Under the simple DRL 16 sec schedule of reinforcement, with the mediating lever still inoperative, IRT distributions typical of DRL schedules were obtained (top set of graphs). The distributions improved markedly when the concurrent (mediating) schedule of food reinforcement was in effect on the mediating lever (middle set of graphs). The improvement took the form of reductions in the proportion of premature (prior to 16 sec) and late (after 20 sec) responses.

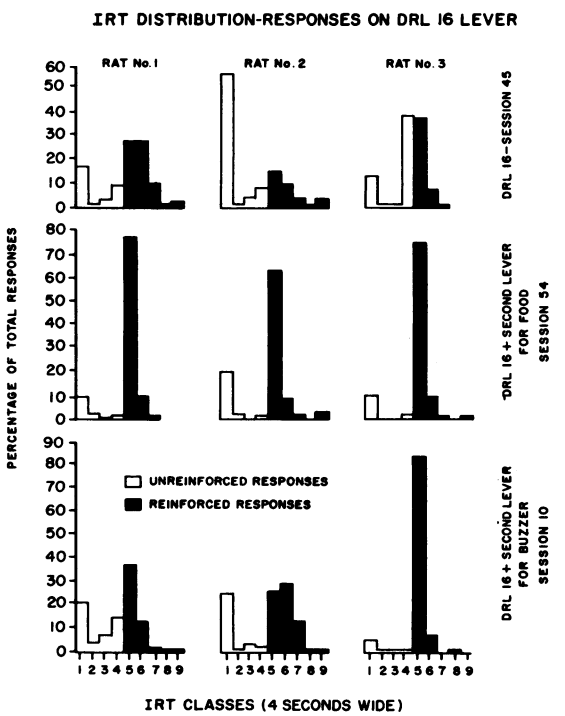

Fig. 2. IRT distributions of DRL responses in Experiment 1.

The bottom set of graphs shows the IRT distributions when mediating-lever responses were reinforced only by buzzer-onset correlated with timing out of the DRL interval. Rat No. 1's distribution was not as sharp as in the just-preceding procedure, but was clearly sharper than under simple DRL 16. Rat No. 2's distribution is only slightly different from that under the previous procedure. Rat No. 3's distribution was virtually identical with its IRT distribution in the just-preceding stage.

These distributions confirm Sidman's observation (1956) that "bursting" under DRL schedules becomes more and more likely as the time since the previous DRL response increases, up to but not including the minimum DRL reinforcement interval. In the present case the probability of a burst of DRL-lever responses was directly related to the probability of a premature DRL response. As the proportion of premature DRL responses was reduced by the introduction of the mediating behavior, the proportion of closely-spaced DRL responses was correspondingly reduced.

EXPERIMENT 2: DRL 24, DRL 60 AND MISCELLANEOUS PROCEDURES

Experiment 1 demonstrated the feasibility of explicitly establishing overt behavior as a mediator of DRL responses, and the sufficiency of conditioned reinforcement to maintain the mediating behavior. Experiment 2 explored the effect of some further experimental manipulations on the strength of the mediating behavior.

Method

First, the DRL requirement on the DRL lever was lengthened from 16 sec to 24 sec. All other relations among response and reinforcement contingencies remained the same. Rat No. 1 received five sessions; Rats No. 2 and No. 3, two sessions.

Next, the DRL requirement was lengthened to 60 sec for three sessions.

In the next stage, a new complication was added. The DRL requirement on the DRL lever was reduced from 60 sec to 50 sec. However, the time of buzzer-onset for a mediating-lever response was not changed, and remained at 60 sec since the previous DRL response. Two alternative routes to food reinforcement now existed: (1) DRL-lever responses spaced at least 50 sec apart were food-reinforced, but no cue signaling the passage of 50 sec was available. (2) If no DRL response occurred for at least 60 sec, a mediating-lever response turned on the buzzer, signaling a reliable reinforcement opportunity on the DRL lever.

An important effect of the 10-sec disparity between the minimum food-reinforceable DRL-lever IRT of 50 sec and the minimum buzzer-reinforceable DRL-lever IRT of 60 sec was that it now became more likely that a switch from the mediating lever to the DRL

lever would be reinforced even in the absence of the buzzer cue.

This procedure, entitled 60-Buzzer-Reinforcement, 50-Food-Reinforcement (60B50F) continued for three sessions.

The final stage of the experiment was a miscellaneous category and each animal was treated differently.

Rat No. 1. In an attempt to recover mediating-lever responding, which had disappeared when the DRL was lengthened to 60 sec, the DRL was shortened to values ranging from 3 sec to 18 sec for single sessions.

Rat No. 2. In an attempt to recover mediating-lever responding, which had lapsed under the 60-Buzzer-Reinforcement, 50-Food-Reinforcement procedure, this animal was returned to the conditions where the food-DRL and the buzzer-DRL requirements were equal at 60 sec each. One session was run.

Rat No. 3. The food-DRL requirement was shortened still further, from 50 sec to 40 sec, while the buzzer-onset-DRL requirement was held at 60 sec. One session was run.

Results

Rat No. 1. Mediating-lever responding, and chaining of mediating-lever-DRL-lever behavior, gradually extinguished as the DRL was lengthened from 16 to 24 to 60 sec. During single, consecutive sessions at DRL 6, 12, 18 and 3, mediating-lever responding, and chaining, recovered at the beginning of each session, but deteriorated during the session.

Rat No. 3. The curve labeled 24B in Fig. 1 shows Rat No. 3's performance on DRL 24. The record is similar to those seen at DRL 16 for this animal. At *a* and *b* appear instances of the rare failures to receive DRL-reinforcement via the two-lever chain.

The curve labeled 60B in Fig. 1 shows Rat No. 3's mediating-lever responding in the final (third) session of DRL 60. When this animal was first put on DRL 60, chaining began to extinguish, and almost disappeared in a second session. Consequently, following the second session, a reconditioning session was run, in which the DRL was reduced to 30 sec and then gradually lengthened to 48 sec. Chaining recovered during the reconditioning session, and remained good in the third session of DRL 60 sec, shown in Fig. 1. The scalloping of mediating-lever responding is easily visible in this record.

Rat No. 3's performance on 60-Buzzer-Reinforcement, 50-Food-Reinforcement is not shown, as it was indistinguishable from its performance on DRL 60. The section of Fig. 1 labeled 60B40F shows Rat No. 3's mediating-lever performance in the session in which the DRL requirement for buzzer-onset was still 60 sec, but the DRL requirement for food had been reduced to 40 sec. Mediating-lever responding extinguished. The extinction record resembles in many respects extinction following fixed-interval food-reinforcement (Skinner, 1938).

Rat No. 2. Rat No. 2's performance at DRL 24 and DRL 60 was similar to Rat No. 3's, although chaining was not quite as regular, and mediating-lever responding was at a lower rate.

The curves labeled 60B50F in Fig. 3 show the result of shortening the DRL food requirement to 50 sec, while holding the DRL buzzer requirement at 60 sec. The record is for the first session on this procedure. Arrows indicate failures of the chain. Failures became more and more frequent as the session progressed, and mediating-lever responding largely extinguished. As chaining began to fail, DRL-lever food-reinforcements became increasingly rare, indicating poor timing in the absence of the buzzer cue. The succeeding two sessions of this procedure completed the extinction of behavior on the mediating lever.

The curves labeled 60B in Fig. 3 show the recovery of mediating-lever responding, and chaining, when Rat No. 2 was returned to the conditions where the DRL requirement on both levers was equal at 60 sec.

The recovery of mediating behavior in this session demands comment. The relation between buzzer-onset and food-reinforcement for a DRL-lever response was not different here from that holding in the 60B50F condition. In both cases the buzzer was invariably correlated with an immediate reinforcement for a DRL response. Furthermore, the frequency of food reinforcement for a DRL response in the absence of the buzzer was only slightly different in the two cases, as timing behavior was not noticeably better at a DRL-for-food requirement of 50 sec than it was at a DRL requirement of 60 sec. While the absolute frequency of food reinforcement for a DRL response in the absence of the buzzer was

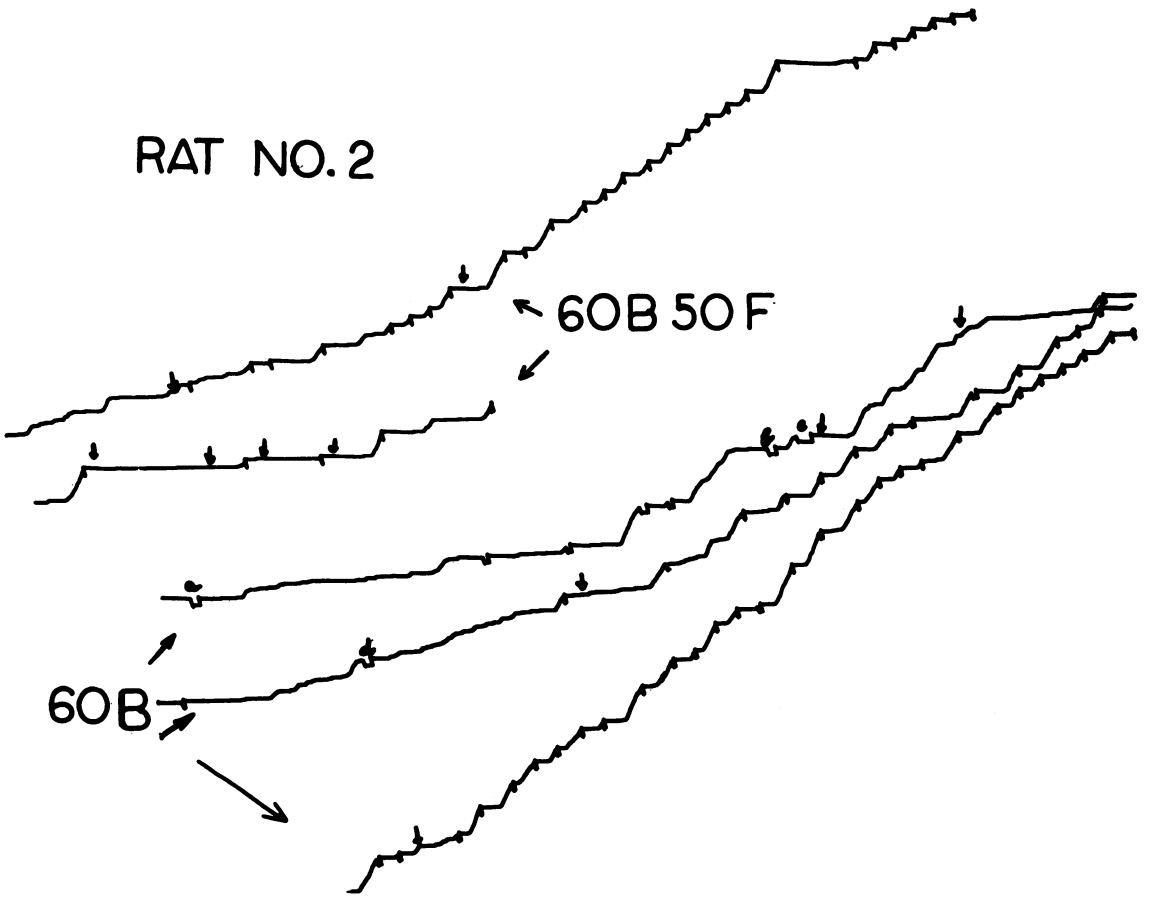

Fig. 3. Rat No. 2: Cumulative response records of responding on the mediating lever.

about the same in both cases, the likelihood of a food-reinforcement for switching from the mediating lever to the DRL lever before buzzer-onset was relatively much greater where the food-DRL was 50 sec and the buzzer-DRL was 60 sec. (For example, if the frequency of food-reinforcement in the absence of the buzzer had increased from two per hour to six per hour, this would represent a small absolute increase in reinforcements-per-hour, but a three-fold increase in the likelihood of a food reinforcement for early switching from the mediating lever to the DRL lever.) The performance shown in Fig. 3 seems to reflect the powerful effect of this difference in probability of food reinforcement for switching in the absence of the buzzer.

Figure 4 presents IRT distributions of DRL responses under the various conditions of Experiment 2. The size of the IRT class-interval differs at different DRL values, and is indicated along the abscissa. The set of numerals appearing at the top of each IRT distribution refers to the value of the DRL requirement and to the session number. For example, 50",60"-3 indicates that the DRL requirement for food was 50 sec, the DRL requirement for buzzer-onset was 60 sec, and that it was the third session of this procedure.

Wherever mediating behavior was strong, and chaining good, a large proportion of DRL responses occurred exactly in the first reinforced IRT interval. Failure of chaining can be immediately detected by picking out the distributions where this was not the case, for example, 60"-1 for Rat No. 1, 50",60"-3 for Rat No. 2, and so on.

Discussion

The persistence of responding on the mediating lever during Experiment 1 and early parts of Experiment 2 is not surprising, in light of the shaping procedure used, and the reinforcement contingencies holding through-

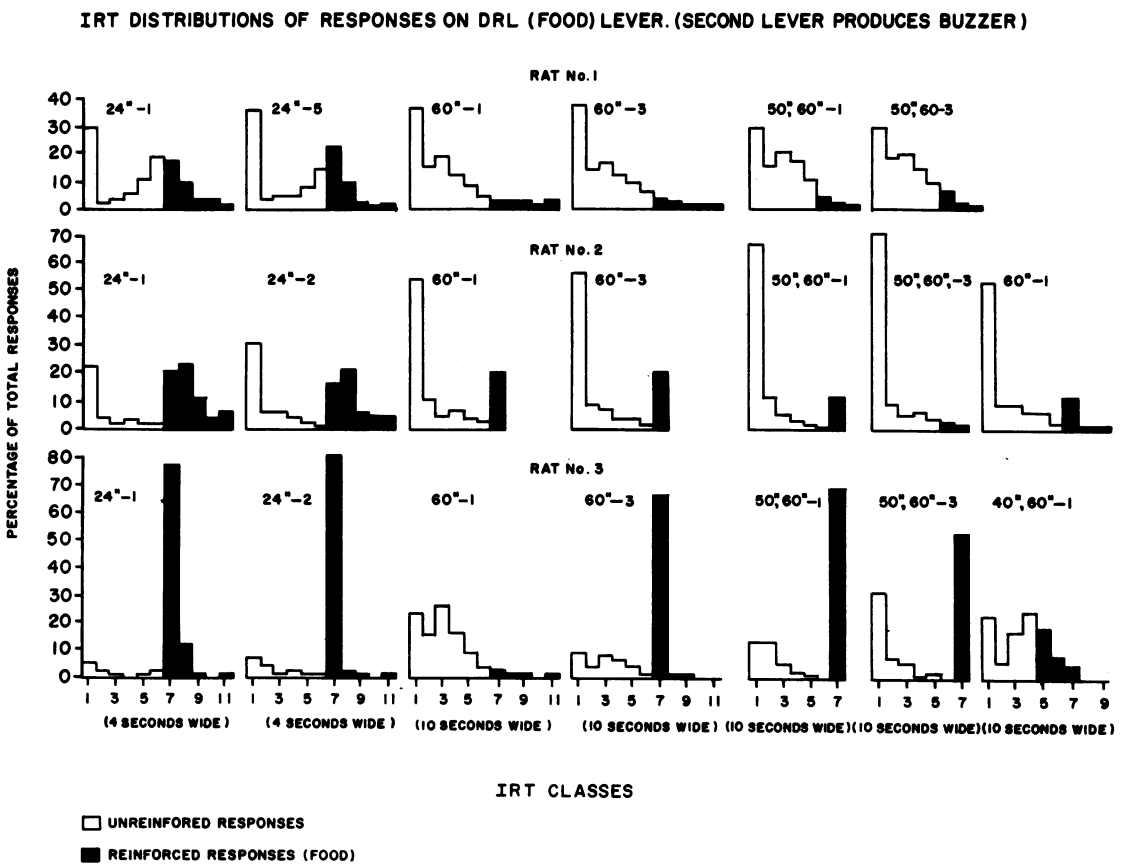

Fig. 4. IRT distributions of DRL responses in Experiment 2.

out both experiments. Although the shaping procedure has been called an "optional chain," and the two main components of the chain have been described as a fixed-interval for conditioned reinforcement, and a DRL for primary reinforcement, it is obvious that the reinforcement contingencies effectively eliminated the DRL schedule altogether. Furthermore, the "optional" character of the chaining requirement was irrelevant to the behavior of the experimental subjects.

The behavioral sequence generated by the experimental conditions can be analyzed into a four-member chain, involving: (1) responding on the mediating lever; (2) switching to the DRL lever; (3) switching away from the DRL lever; and, (4) returning to the mediating lever.

Component (1) was reinforced according to a fixed-interval schedule of primary or conditioned reinforcement. Component (2) was a discriminative operant, reinforced, in the presence of the appropriate S^D, (the buzzer), on a continuous food-reinforcement schedule.

That switching from the DRL lever and returning to the mediating lever were separate and distinct behaviors is borne out by the scalloping of behavior on the mediating lever. Following a DRL-lever reinforcement, mediating-lever responding did not resume immediately. Some other behavior, not recorded in the experiment, must have intervened. Whether this additional mediating behavior assumed some regular pattern is not known, but the finding emphasizes the ubiquity of varieties of mediating behavior, and the difficulties in rendering all of them explicit.

The gradual weakening of mediating-lever behavior in Experiment 2 requires explanation. The principal reinforcement contingencies were the same under DRL 16, DRL 24 and DRL 60. In all cases, conditioned reinforcement according to a fixed-interval schedule continued in effect on the mediating lever.

In all cases, primary reinforcement according to a continuous reinforcement schedule in the presence of the appropriate S^D (the buzzer) continued in effect on the DRL lever.

The simplest explanation for the weakening of behavior on the mediating lever is that conditioned reinforcement is not so effective as primary reinforcement in maintaining fixed-interval behavior. As mediating behavior weakened even slightly at longer DRL values, the probability of a premature switch to the DRL lever increased. As premature switching increased, the subjects reinstated the DRL schedule of food reinforcement on the DRL lever, and, incidentally, prolonged the inter-reinforcement interval on the mediating lever. Primary and conditioned reinforcement became less frequent. As reinforcement became less frequent, the mediating behavior weakened even more, resulting in still fewer reinforcements. A spiraling process of gradually weakening behavior, and progressively fewer reinforcements, occurred.

The progressive weakening of experimental control was exaggerated under the conditions where the DRL lever could produce food reinforcement after shorter inter-response delays than the mediating lever could produce conditioned reinforcement. Here, for the first time, there was a sharp increase in the likelihood that a premature switch from the mediating lever to the DRL lever would be reinforced with food. Even occasional food-reinforcements for DRL responses in the absence of the buzzer would be expected to weaken the discriminative control of the buzzer, and hence its conditioned reinforcing properties. Another factor was added to the spiraling process, and, eventually, the complex chain of behavior extinguished.

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