

*INTER-RESPONSE TIME DISTRIBUTION AS A FUNCTION OF
DIFFERENTIAL REINFORCEMENT OF TEMPORALLY
SPACED RESPONSES*

ROGER T. KELLEHER, WILLIAM FRY, and
LEONARD COOK

SMITH, KLINE & FRENCH LABORATORIES

In his analysis of temporal discriminations, Skinner (1938) described an experiment in which the response rates of rats were decreased by reinforcing only inter-response times (IRT's) which exceeded 15 seconds (p. 306). Wilson and Keller (1953) confirmed and extended this finding by demonstrating that the rate of responding is inversely related to the duration of the minimum required IRT. This type of schedule of reinforcement is referred to as the "differential reinforcement of low response rates" (DRL). Recent investigations indicate that DRL schedules engender temporal discriminations which can be analyzed by means of the relative-frequency distribution of IRT's or the distribution of response probabilities (Anger, 1956; Sidman, 1956).

On DRL schedules of reinforcement, each response starts the required delay interval. Responses which occur before the delay interval has elapsed not only are unreinforced but they also postpone reinforcement by starting a new delay interval. To the extent that the animal can discriminate the delay interval; these two contingencies should eliminate responding during the delay interval. Wilson and Keller (1953) reported that their rats adapted to the DRL schedule by developing various chains of overt behavior which persisted between lever presses and which occupied enough time so that the lever presses following the chains were reinforced.

More recent investigations, which include detailed analyses of the temporal response patterns which develop on DRL, have consistently indicated that a large proportion of IRT's occur at about 0-3 seconds (Conrad, Sidman, & Herrnstein, 1958; Sidman, 1955; Sidman, 1956a; Sidman, 1956b). These short IRT's result from frequent "bursts" of responding, and they generate IRT relative-frequency distributions and probability distributions which are bi-modal. One mode occurs in the vicinity of the minimum IRT which is required for reinforcement; the second mode, which is a result of these bursts, occurs at about 0-3 seconds. Sidman presented evidence indicating that the probability of a burst was high near the minimum IRT required for reinforcement. He suggested that "late in the delay period, a single lever press often fails to reset the animal's 'clock,' with the result that several quick responses are emitted" (Sidman, 1956a, p. 472).

A very precise control of the rate of responding can be developed by reinforcing only those IRT's which fall within a specified range (Ferster & Skinner, 1957, pp. 498-502); that is, a reinforced IRT must not only be longer than some minimum value (as in DRL) but also shorter than some maximum value. Thus, reinforcements are available for only a limited period of time. This type of schedule is referred to as DRL with a "limited hold" (DRL LH). For example, on DRL 20 LH 3, only responses which are emitted between 20 and 23 seconds after a preceding response will be reinforced; responses emitted at less than 20 seconds or more than 23 seconds after a preceding response start the timing interval again. On DRL LH

schedules, the development of chains of behavior should be less probable since the animal must discriminate a discrete point on the temporal continuum. The time occupied by overt behavior other than lever-pressing could occupy enough time to enable the animal to meet the minimum requirement; but this chain of responses would be unreinforced whenever it extended beyond the maximum requirement. There is little available evidence pertaining to the temporal characteristics of behavior developed and maintained on DRL LH schedules. Data presented by Conrad, Sidman, and Herrnstein (1958) indicated that a large proportion of very short IRT's occurred on DRL 20 LH 2 and DRL 20 LH 4.

The present paper reports an investigation of the development and maintenance of behavior on DRL and DRL LH schedules of food reinforcement. The effects were investigated of reducing the frequency of reinforcement, imposing very brief "limited holds," and of minimizing the distinctiveness of "response-produced stimuli." The performances of animals with different experimental histories were investigated over a prolonged period of time on a DRL 18 LH 3 schedule.

METHOD

The subjects were adult, male, albino rats maintained at about 65% of their estimated free-feeding weights. The rats had been trained to press a lever to obtain 94-milligram food pellets. Each depression of the lever activated the recording and controlling circuits, and produced an audible relay "click" in the experimental chamber. Immediately after each response which was to be reinforced, a loud magazine sound occurred. Experimental sessions of one or two hours' duration were conducted daily from Monday through Friday. The food-deprivation regimen was maintained on weekends.

Responses and reinforcements were recorded by electrical-impulse counters and a cumulative-response recorder. Ten counters tabulated IRT's ranging from 0 to 30 seconds in class intervals of 3 seconds; an eleventh counter tabulated all IRT's of more than 30 seconds. Both IRT relative-frequency distributions and response-probability distributions were computed from these IRT tabulations. The IRT relative-frequency distributions were established by dividing the total number of responses in the session into the number of responses in each 3-second class interval (Anger, 1956; Sidman, 1956a). The response probability was computed by dividing the possible number of responses in each class interval into the actual number of responses in that class interval. The latter quotient provides an independent estimate of the probability of a response in any class interval, assuming that the animal paused long enough to reach that class interval (Anger, 1956). For example, if 100 responses out of a total of 200 responses occurred in the first class interval (0-3 seconds), only 100 responses could possibly have occurred in the second class interval (3-6 seconds). If only 20 responses actually occurred in the second class interval, the response probability would be 0.20. The corresponding relative frequency would be 0.10. Anger (1956) has thoroughly discussed the advantages and disadvantages of each type of distribution.

Experimental sessions were 2 hours long. Because the recording equipment was not complete in the early sessions, the initial development of performances will not be presented.

RESULTS

DRL 20 LH 3

The performances which had developed after 40 hours on DRL 20 LH 3 are presented in the cumulative-response records, relative-frequency distributions of IRT's, and probability distributions of Fig. 1. Coordinates and a slope corresponding to a response rate which would maximize reinforcements are presented in the lower right corner of Fig. 1.

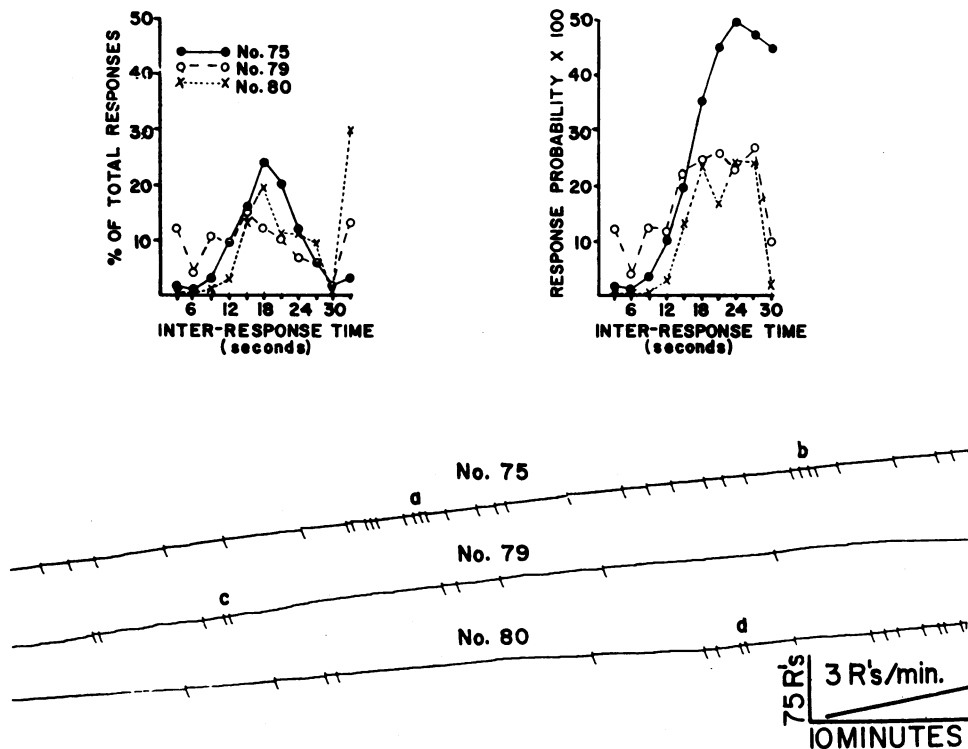


Figure 1. Final performances on DRL 20 LH 3. Upper right: response-probability distributions. Bottom: cumulative-response records, with pips indicating reinforced responses.

The cumulative-response records at the bottom of the figure reveal the high variability in the individual rates of responding on DRL 20 LH 3. Reinforced responses often occurred in sequences, as shown at *a*, *b*, *c*, and *d*. The relative-frequency distributions at the upper left of Fig. 1 also reflect the individual differences in rates of responding. The distribution of No. 75 is symmetrical around a mode at 15-18 seconds. The distributions of No. 79 and 80 also have modes in this region; however, both of these animals had many IRT's at more than 30 seconds, while No. 79 had many IRT's at 0-3 seconds. The probability distributions (upper right of Fig. 1) are all characterized by clear increases in response probability as a function of time since the preceding response; however, the distributions of No. 79 and 80 are relatively flat. Following the session shown in Fig. 1, the schedule was

changed to DRL 20 LH 5 to facilitate the development of more stable performances.

DRL 20 LH 5

Over the first 20 experimental hours on this schedule, the number of reinforced responses increased steadily for each subject. The performances which had developed after 25 hours on DRL 20 LH 5 are presented in Fig. 2. The response rates were stable from session to session and were consistent between animals. Reinforced responses tended to occur in relatively long sequences. For example, at *a*, *b*, and *c* the numbers of successive reinforced responses are 8, 12, and 4, respectively.

The relative-frequency distributions of IRT's in Fig. 2 (upper left) show that responses are symmetrically distributed around modes at 18–21 seconds. These distributions are similar to those which have been presented by other investigators (Conrad, Sidman, & Herrnstein, 1958; Sidman, 1955; Sidman, 1956a) in that the modal IRT frequency occurs at a time interval which is shorter than the required delay interval. However, the distributions presented in Fig. 2 have a single mode, while those of Conrad, Sidman, and Herrnstein (1958) had a second mode at the

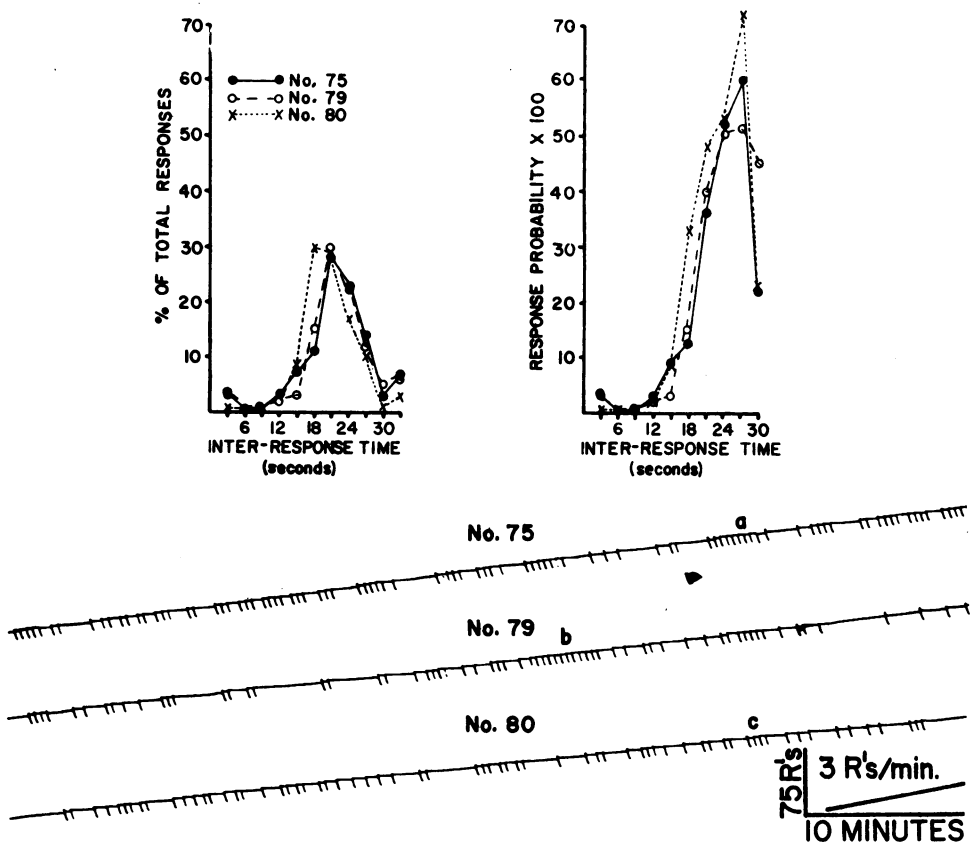


Figure 2. Performances on DRL 20 LH 5. Upper left: relative-frequency distributions of IRT's. Upper right: response-probability distributions. Bottom: cumulative-response records.

shortest class interval (Conrad, Sidman, & Herrnstein, 1958; Sidman, 1955; Sidman, 1956a). It should be noted that 75 and 79 consistently tended to have a percentage of 0–3-second IRT's which was slightly higher than those in the neighboring class intervals; however, this percentage seldom exceeded 5%. The extent to which the animals had adjusted to the temporal contingencies of the DRL 20 LH 5 schedule is most clearly demonstrated by the probability distributions of Fig. 2 (upper right). The probability of a response remained low (less than 0.10) for the first 15 seconds after a preceding response, but then rose abruptly to a high value (more than 0.50) in the 21–24-second class interval. The decreased response probability in the 27–30-second class interval occurred consistently. Following the session shown in Fig. 2, all animals received one session of experimental extinction.

Extinction

The performances in extinction are presented in Fig. 3. Although the response rates were lower, all animals continued to respond throughout the 2-hour extinction sessions. The "pips" on the cumulative records indicate responses that would have been reinforced on DRL 20 LH 5. It is apparent that the sequences of appropriately spaced responses still occur (as at *a*, *b*, and *c*), but have been reduced in both number and length. The probability distributions have retained their general characteristics; however, probabilities of responses in the 9–12- and 12–15-second class intervals have increased slightly, while the probabilities in the longer class intervals have

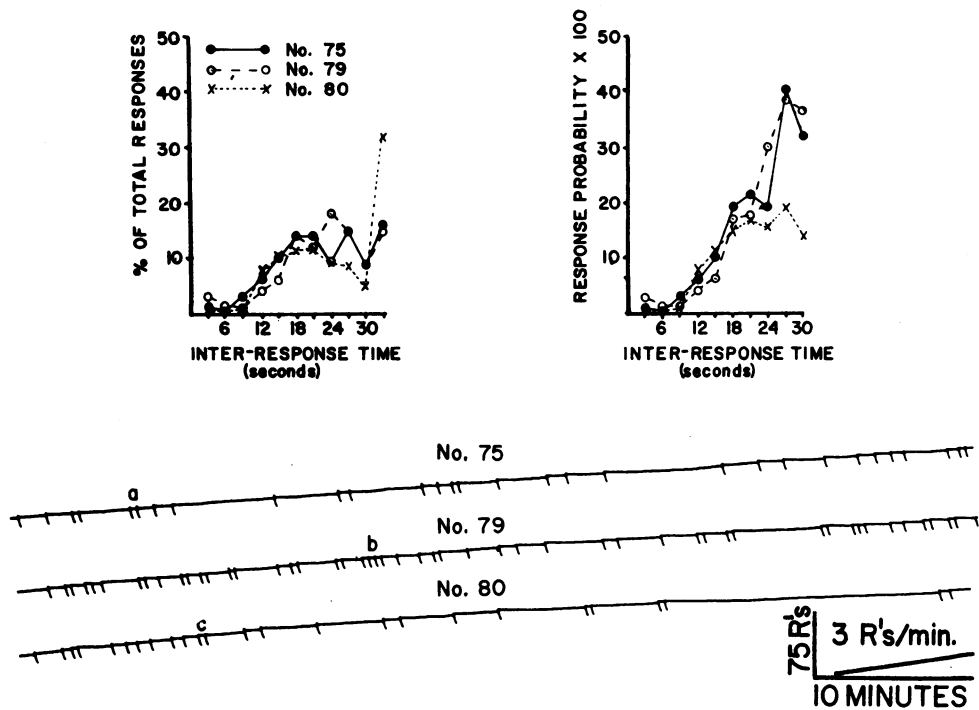


Figure 3. Extinction after DRL 20 LH 5. Upper left: relative-frequency distributions of IRT's. Upper right: response-probability distributions. Bottom: cumulative-response records, with pips indicating responses that would have been reinforced on DRL 20 LH 5.

decreased. Extinction did not produce bursts of responding which would increase the probability of responses in the 0-3-second class interval.

Within 6 hours after the extinction session, all animals had returned to performances comparable with those shown in Fig. 2. At this time, an additional requirement was added to the DRL 20 LH 5 schedule; the animals were reinforced only for every second IRT (not necessarily in succession) which fell between 20 and 25 seconds. We will refer to this requirement as a 2-response fixed-ratio (FR 2). Under this procedure, the number of reinforcements obtained for a given level of performance would be 50% of the number obtained under DRL 20 LH 5.

DRL 20 LH 5 FR 2

The addition of FR 2 to DRL 20 LH 5 produced performances which were stable over the 10 experimental hours that the procedure was in effect. Cumulative-response records and probability distributions from the tenth hour are presented in Fig. 4. The response rates decreased slightly, and the reinforcements were more

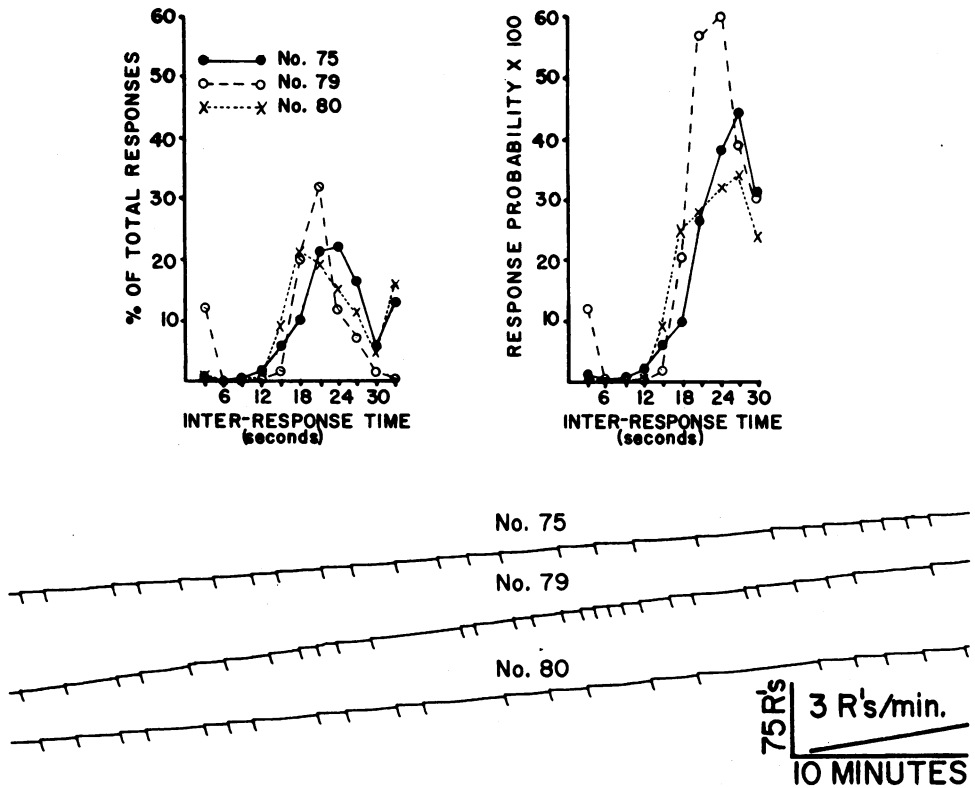


Figure 4. Final performance on DRL 20 LH 5 FR 2. Upper left: relative-frequency distributions of IRT's. Upper right: response-probability distributions. Bottom: cumulative-response records, with pips indicating reinforced responses.

evenly distributed over each session. The percentages of reinforced responses dropped to slightly below 50% of the levels maintained on DRL 20 LH 5, indicating

that the efficiency of the animals' performances had not deteriorated. The probability distributions indicate that No. 79 developed patterns of responding on FR 2 which differed from those of the other two rats. The response probabilities between 0 and 18 seconds were unchanged for No. 75 and 80; however, the probability of responses in the 0-3-second class interval increased for No. 79. In the class intervals between 18 and 30 seconds, the response probabilities on DRL 20 LH 5 FR 2 were lower than on DRL 20 LH 5 for No. 75 and 80, but were not much changed for No. 79. An FR 4 requirement was imposed on the DRL 20 LH 5 in the following session. Under this condition, all animals ceased responding within 6 hours. When returned to DRL 20 LH 5, all Ss rapidly recovered performances similar to those shown in Fig. 2.

The animals showed only a slight tendency to respond in bursts under our experimental conditions. Possibly, the auditory feedback which accompanied each response provided distinctive "response-produced stimuli" at the start of each delay interval which reduced the tendency to emit several quick responses. We tested this possibility in a subsequent session by eliminating the auditory feedback.

Effects of Removing Auditory Feedback

After more than 120 hours on the DRL 20 LH 5 schedule, the animals were spacing their responses with remarkable precision. Representative response-probability distributions are shown in the "feedback" curves of Fig. 5. For example, the distribution of No. 75 shows that the probability of a response remained at 0.00-0.03 for the first 18 seconds after a preceding response, and then increased abruptly to 0.60 at 21-24 seconds and 0.83 at 24-27 seconds. In this case, the response probability was so high at 24-27 seconds that longer responses were too infrequent to permit a reliable estimate of the response probability at 27-30 seconds.

When the auditory feedback was eliminated in the following session, the response rates of all animals became slightly higher. Response probabilities had increased at 0-3 seconds for No. 75 and 79 and at 15-18 seconds for all animals; the response probability for No. 75 at 21-24 seconds had decreased. The effects of removing the auditory feedback were consistent; however, the magnitude of the effect was not large at the short IRT's.

Responses before the required minimum delay have been extinguished by non-reinforcement. Thus, any changes in stimulus conditions following a response could be expected to produce some "spontaneous recovery" or "disinhibition." Nevertheless, removal of the auditory feedback produced only slight increases in early responding.

DRL 20 LH 1

After about 150 hours on DRL 20 LH 5, the effects of imposing a very short limited hold were assessed by abruptly shifting the animals to DRL 20 LH 1. The animals remained on DRL 20 LH 1 for about 30 hours. Cumulative-response records and corresponding response-probability distributions for the last sessions on DRL 20 LH 5 and DRL 20 LH 1, respectively, are presented in Fig. 6.

The probability distributions on DRL 20 LH 5 showed that only No. 75 still had a slightly higher probability of a response in the 0-3-second class interval than in the neighboring class intervals. Occasional quickly repeated responses usually oc-

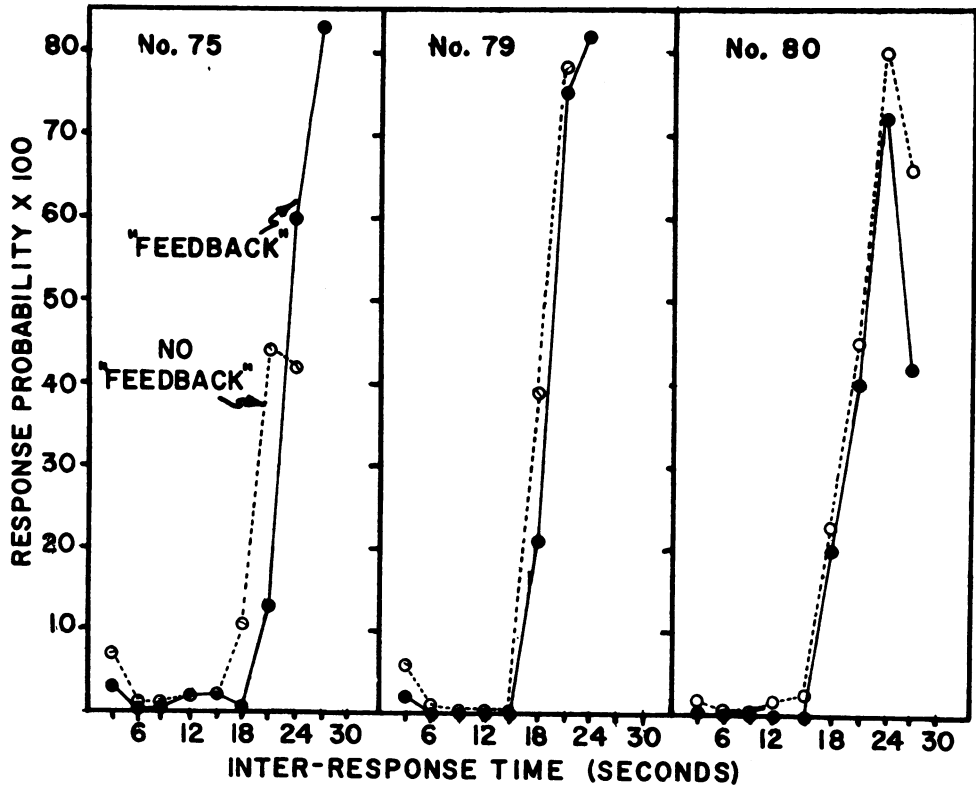


Figure 5. Response-probability distributions from session on DRL 20 LH 5 with auditory feedback accompanying each response (solid lines), and from following session on DRL 20 LH 5 without auditory feedback (dashed lines).

curred when this animal did not succeed in obtaining reinforcement for a relatively long period of time (as at *a*). The cumulative records of all animals on DRL 20 LH 5 were still characterized by long sequences of successively reinforced responses (at at *b*, *e*, and *g*).

When the schedule was changed from DRL 20 LH 5 to DRL 20 LH 1, the percentages of reinforced responses decreased from more than 50% to about 10%. The cumulative records showed that all animals maintained slightly higher average response rates on DRL 20 LH 1 than on DRL 20 LH 5. These average response rates remained close to 3 responses per minute. Short sequences of reinforced responses did still occur. Response rates tended to increase when reinforcements were infrequent (as at *c*, *d*, *f*, and *h*).

All animals maintained continuous performances on DRL 20 LH 1, and there was every indication that behavior could be maintained indefinitely with this brief limited hold. Frequent observations of the animals did not reveal any chains of overt behavior between lever presses.

DRL 20 without Auditory Feedback

The purpose of this experiment was to study the development of behavior on DRL 20 without any limited hold and without any auditory feedback for responses.

Two naive rats were trained to press the lever, received 20 reinforcements on crf, and were then shifted directly to DRL 20. Experimental sessions were 2 hours long.

The IRT relative-frequency distributions and probability distributions for one animal are presented in Fig. 7. Comparable results were obtained with the other animal. The frames on the left of the figure are from Session 1 on DRL 20, while those on the right are from Session 30. The relative-frequency distributions (top of Fig. 7) indicate that upon initial exposure to DRL 20, most IRT's occurred at 0-6 seconds. On the other hand, the corresponding probability distribution (bottom of Fig. 7) reveals that the probability of a response was not correlated with time since a previous response. These results, which are similar to those reported by Anger for initial exposure to VI, show that there was no adjustment to the temporal contingencies of the schedule upon initial exposure (Anger, 1956).

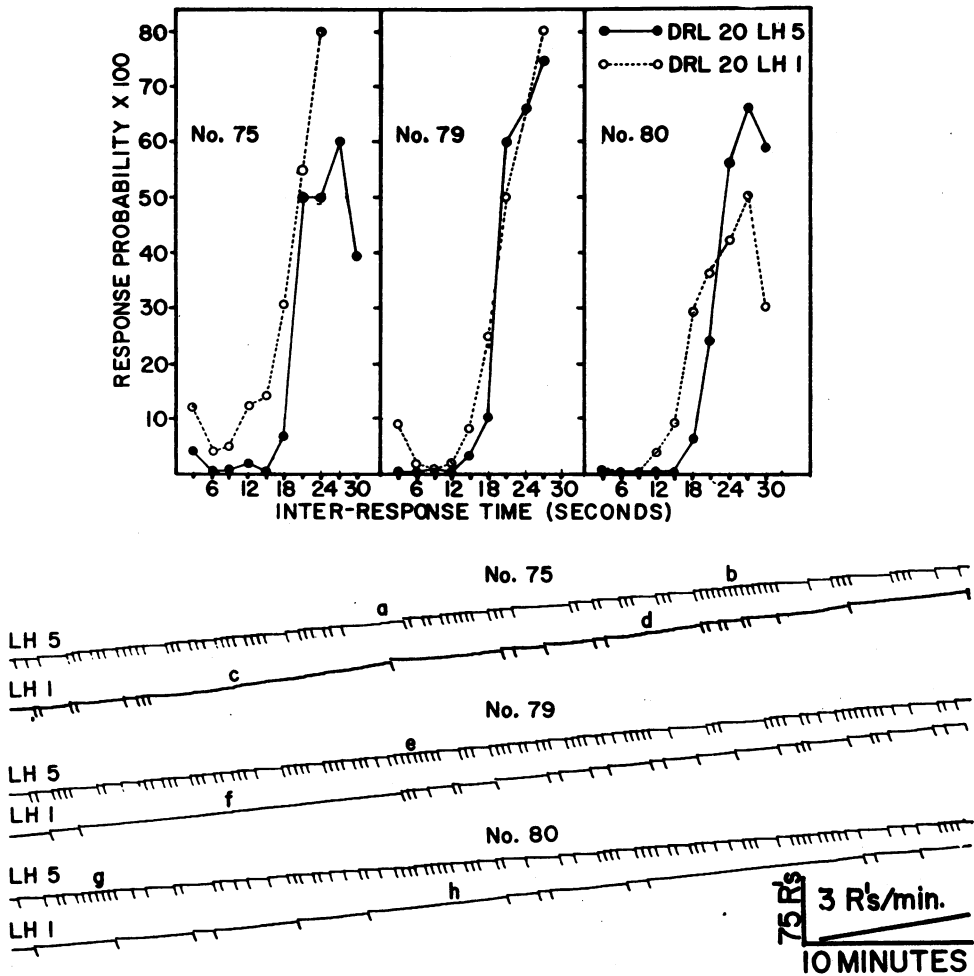


Figure 6. Top: Response-probability distributions from last session on DRL 20 LH 5 (solid lines) and from last session on DRL 20 LH 1 (dashed lines). Bottom: corresponding cumulative-response records.

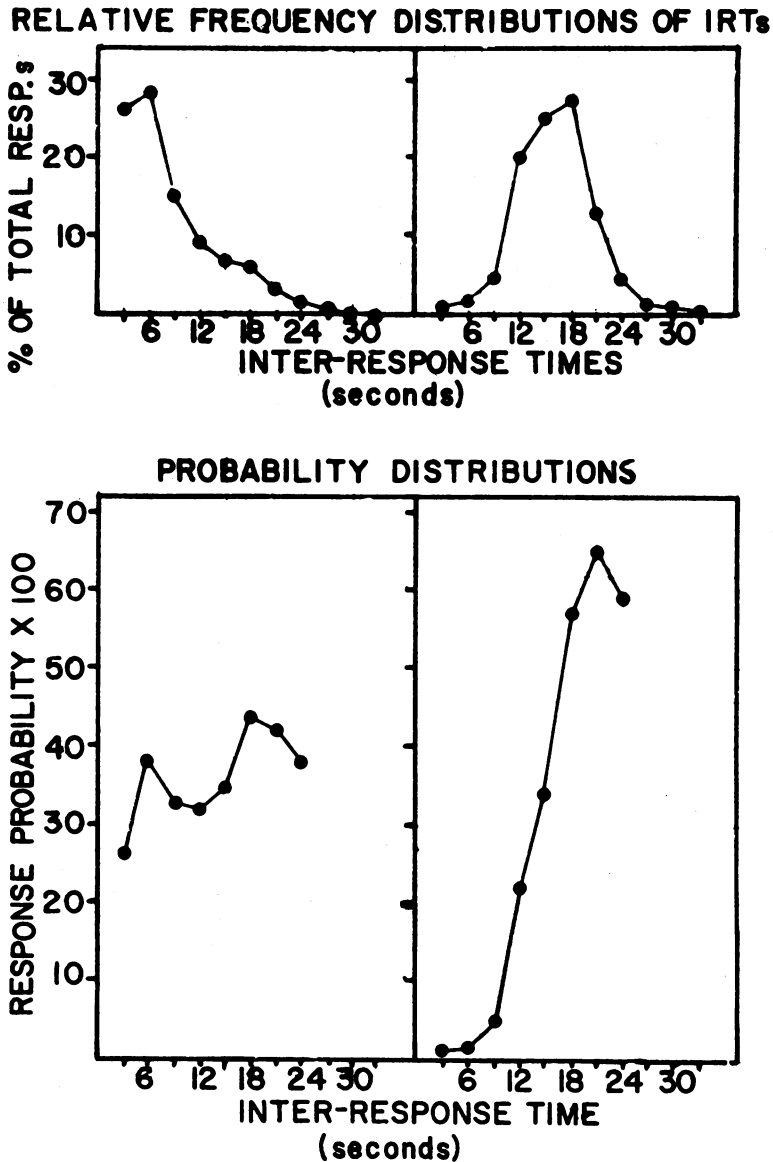


Figure 7. Development of performance on DRL 20 without LH and without auditory feedback. Left panels: Session 1. Right panels: Session 30.

After 30 hours on DRL 20 (frames on the right of Fig. 7), the characteristics of both distributions had been markedly modified. Short IRT's were very infrequent, and the IRT relative-frequency distributions were symmetrical around modes at 15-18 seconds. The efficacy of the adjustment to the temporal contingencies of the schedule is more apparent in the response-probability distribution. As time elapsed from a preceding response, the probability of a response remained low (less than 0.05) over the first 9 seconds and then rose linearly to about 0.65 at 18-21 seconds.

Again, the animals were frequently observed in the experimental situation; however, neither rat developed any regular pattern of responding between lever presses.

This experiment demonstrated that the auditory feedback was not necessary for even the initial development of the characteristic IRT relative-frequency distributions and probability distributions which we have obtained. These results also indicate that the proportion of short IRT's decreases to about zero after many sessions on DRL without LH and without auditory feedback. In the present experimental situation, chains of behavior between lever presses did not develop on either DRL or DRL LH.

DRL 18 LH 3

The characteristics of behavior maintained on DRL 18 LH 3 for extended periods of time were investigated with six rats. Four of these animals had received 20 reinforcements on crf; two animals had experimental histories of about 10 hours on FR 10. All animals started this experiment on DRL 18, and were gradually shifted to DRL 18 LH 3 by progressively shortening the LH as the percentages of reinforced responses increased. Experimental sessions were 1 hour long. Results representative of animals with each type of history (crf or FR) will be presented.

Probability distributions and corresponding cumulative-response records for No. B-22 (history of crf) at four stages of the experiment are presented in Fig. 8. Reinforcements are not indicated. Although the relative frequency of short IRT's was high, the probability of a response as a function of time since a preceding response did not change (cf. Fig. 7). The corresponding cumulative record was characterized by a series of negatively accelerated segments and a relatively high over-all response rate. By Session 6, the over-all response rate was still higher than 3 responses per minute, but it was stable.

The further development of the temporal discrimination was most apparent in changes in the probability distributions. In Session 50, the probability of a response remained at less than 0.03 for the first 12 seconds after a previous response, then rose linearly to a value of 0.74 at 18–21 seconds, and then fell to 0.50 at 24–27 seconds. This is a representative distribution, and it demonstrates the remarkable precision with which these animals were spacing their responses.

Probability distributions and corresponding cumulative records for B-16 (history of FR) at four stages of the experiment are presented in Fig. 9. Upon initial exposure to DRL 18, the probability of response (0.60) within 3 seconds after a previous response was high, but it was relatively low after 3 seconds. The cumulative record for this initial session was characterized by high response rates alternating with pauses and very low rates. By Session 5, the cumulative-response record was characterized by successive negatively accelerated segments, and the corresponding response-probability distribution had its mode at 6–9 seconds. This performance was somewhat similar to that of B-22 upon initial exposure to DRL 18. In Session 50, the probability of a response remained less than 0.07 for the first 15 seconds after a previous response, then rose linearly to a value of 0.59 at 18–21 seconds, but subsequently fell to about 0.46 at 24–30 seconds.

The changes in response probabilities at three discrete intervals after a preceding response were plotted as a function of the number of experimental sessions for No. B-22 and B-16, respectively. These functions are presented in Fig. 10 and 11.

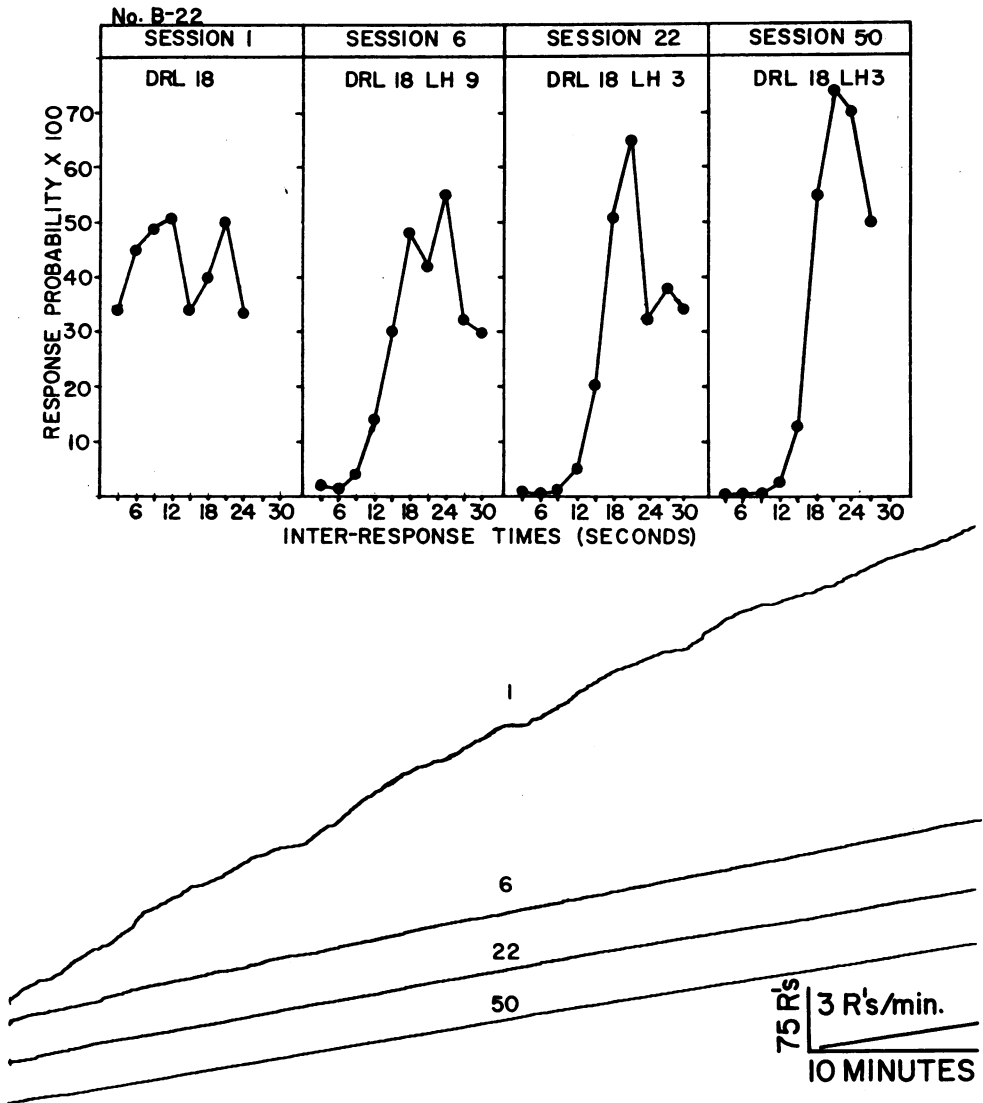


Figure 8. Response-probability distributions and corresponding cumulative-response records showing development of performance on DRL 18 LH 3 after brief history of crf.

It will be recalled that the response probabilities of No. B-22 showed no definite trend upon initial exposure to DRL 18. Figure 10 indicates that the probability of a response at 0-3 seconds after a preceding response had dropped to almost zero by Session 6. The probability of a response at 9-12 seconds after a preceding response fell precipitously over the first few sessions and then declined very gradually to a value of about 0.02 over Sessions 30-70. The probability of responses in the 18-21-second class interval (all responses in this class interval were reinforced) rose irregularly to values between 0.59 and 0.73 over Sessions 22-70.

Upon initial exposure to DRL 18, the probability of a response for No. B-16 was high at 0-3 seconds following a preceding response, but then fell to low values. Figure 11 indicates that the response probability at 0-3 seconds fell rapidly over the first six experimental sessions and then more gradually to almost zero, where it remained over Sessions 20 to 130. This general trend was slowed when the schedule was changed from DRL 18 to DRL 18 LH 9, and was reversed each time the limited hold was further decreased (Sessions 7 and 11). The response probability in the 9-12-second class interval was initially low, but increased to 0.37 in Session 5. After this session, the probability of a response in the 9-12-second class interval de-

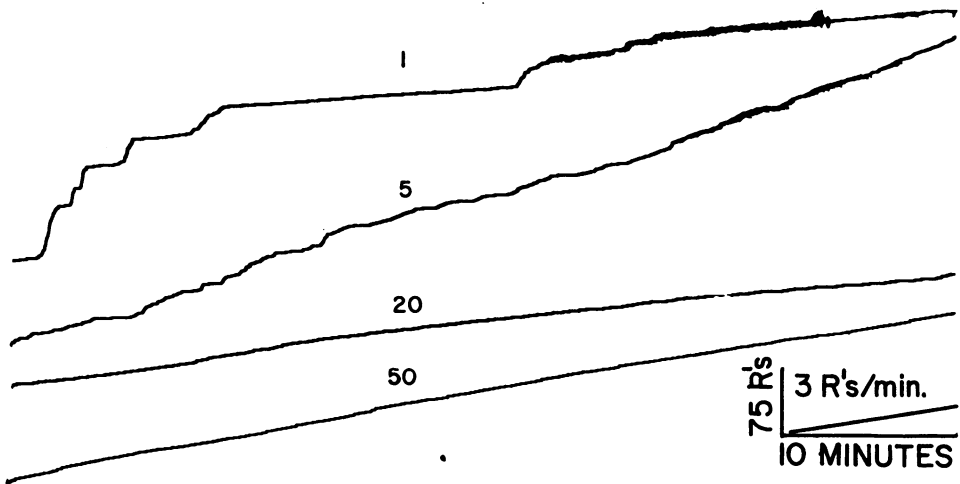
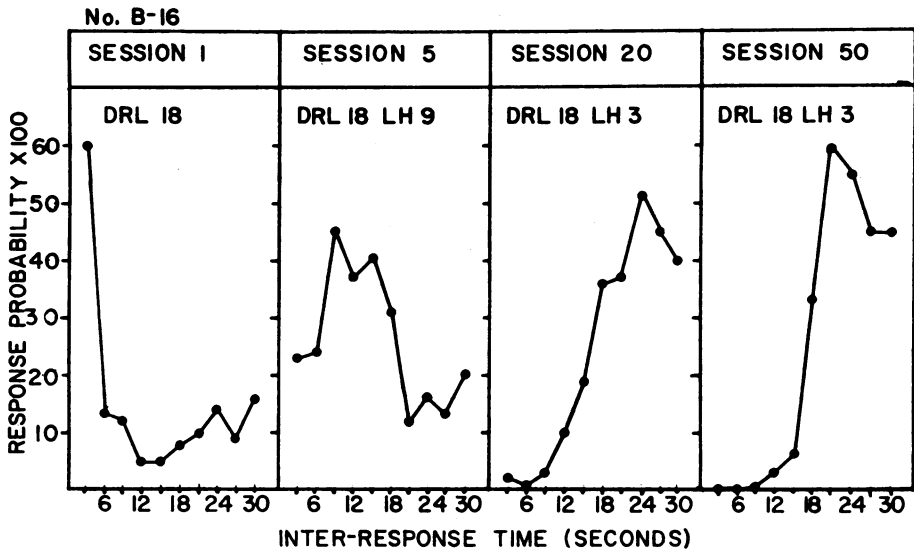


Figure 9. Response-probability distributions and corresponding cumulative-response records showing development of performance on DRL 18 LH 3 after history of FR 10.

creased gradually to a value of about 0.02, where it remained over Sessions 110-130. This trend was temporarily reversed in Session 7, when the schedule was shifted from DRL 18 LH 9 to DRL 18 LH 6. The probability of responses in the 18-21-second class interval rose irregularly from 0.05 in Session 1 to 0.51-0.69 over Sessions 50-130.

These results demonstrate that the early performance on DRL 18 LH 3 depends on the animal's experimental history. As Skinner (1938) notes, FR schedules provide for the differential reinforcement of short IRT's. The animals with FR histories, therefore, had high response probabilities at 0-3 seconds in Session 1. The cumulative records for No. B-16 in Session 1 are similar to those obtained in extinction after FR. Despite the history of differential reinforcement of high response rates on FR, both animals developed response probabilities close to zero at 0-3 seconds after a preceding response.

The results of this investigation indicate that characteristic performances on DRL can be developed and maintained under a variety of experimental conditions. These performances were characterized by low response probabilities following a preceding response; these probabilities increased abruptly as the minimum required delay elapsed. Under both DRL and DRL LH schedules, the response probabilities decreased with the further passage of time after the minimum requirement had been reached.

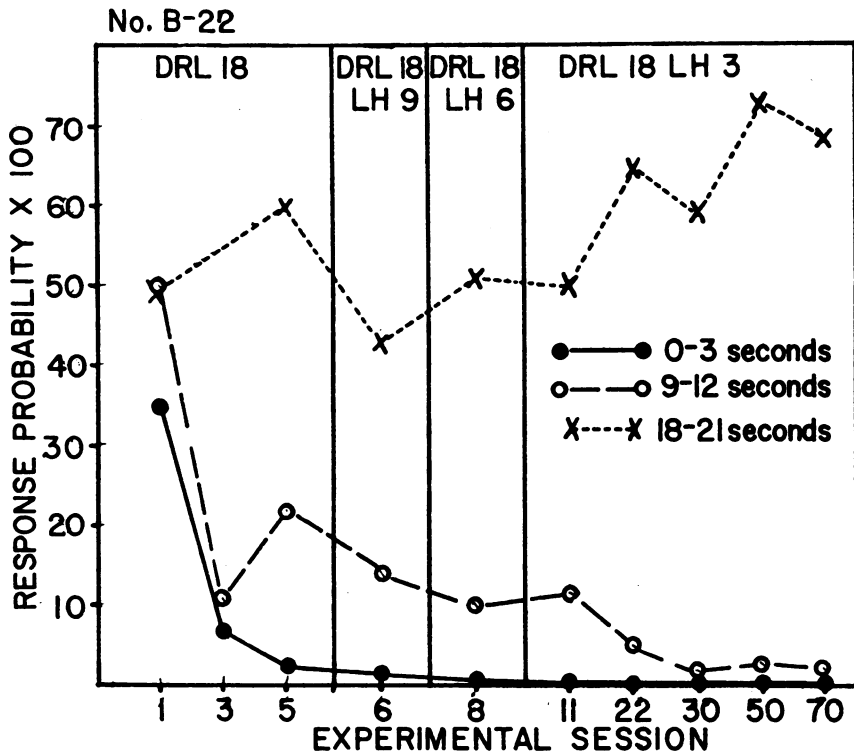


Figure 10. Changes in response probabilities as a function of number of experimental sessions after brief history of crf.

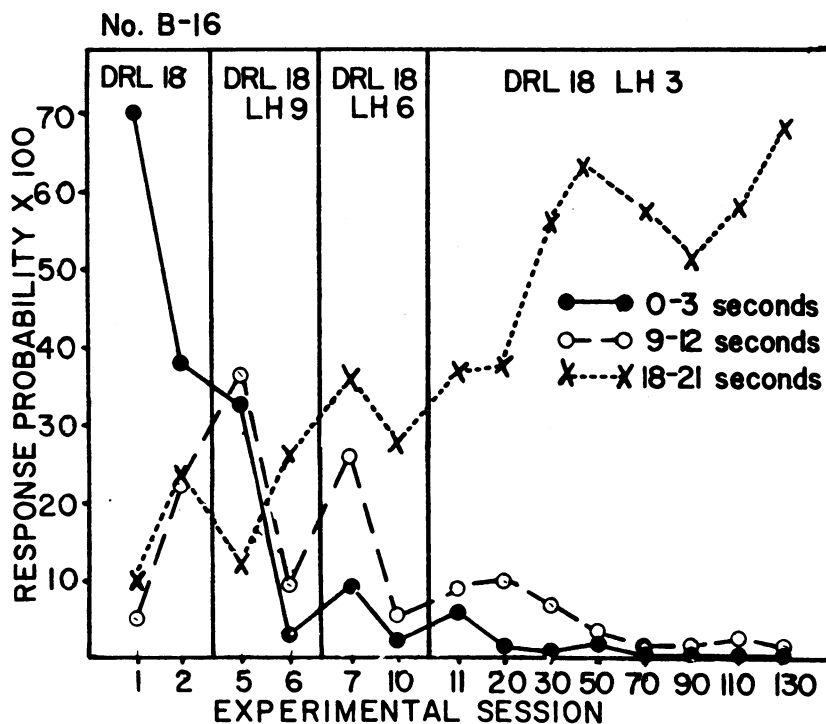


Figure 11. Changes in response probabilities as a function of number of experimental sessions after history of FR 10.

The present results are not in agreement with many of the findings of earlier studies of performance of rats on DRL schedules. These differences are undoubtedly caused by differences in deprivation conditions, reinforcers, or apparatus. For example, those investigators who report a high proportion of very short IRT's have consistently used liquid reinforcers. These reinforcers were delivered by means of a motor-driven cup, and there was probably a discrete period of time during which the cup was rising from the liquid reservoir to the opening where it was made available to the animals. If a response which met the reinforcement requirement were quickly followed by a second response before the cup appeared, this burst would be adventitiously reinforced. This possibility is suggested by Sidman's results (1956a, Fig. 2) from rats on DRL 20. These results showed that the probability of a burst was highest following responses at 18-21 seconds after a previous response. However, since the probability of a burst of responses was also high at 20-22 seconds after a previous response, a large proportion of reinforced responses must have been followed by bursts. In any event, our results indicate that bursts of responding are not an inevitable occurrence on DRL or DRL LH schedules of reinforcement.

How do rats develop such remarkable precision in spacing their responses along a temporal continuum? Our results, as well as those of Anger (1956), indicate that rats can time intervals of 20 seconds or longer with fair accuracy by some means other than a chain of overt responses. As Anger suggests, the rats evidently make use of some internal variable which changes as a function of time since the preced-

ing response. To date, there is not evidence to indicate the mechanism of this "internal clock."

SUMMARY

This investigation demonstrated that precise time discriminations could be established with albino rats by selectively reinforcing responses spaced at specified time intervals from the preceding response. When responses spaced between 20 and 25 seconds from a previous response were selectively reinforced, the probability of a response remained very low for about 15 seconds following a preceding response, and then increased abruptly to a peak near 20 seconds. The general characteristics of this probability distribution were only slightly affected by reducing the percentage of reinforced responses or by removing the auditory stimulus which accompanied each response. When responses spaced 20 to 21 seconds apart were required for reinforcement, the increase in response probability occurred earlier in the delay interval.

The acquisition of temporal discrimination was studied on two schedules. One schedule reinforced responses spaced 18 to 21 seconds apart, and the other reinforced all responses spaced more than 20 seconds from a previous response. When newly trained animals were exposed to either schedule, response probabilities remained intermediate as time elapsed from a previous response. With further experience on either schedule, the response probability became dependent upon time since the preceding response.

None of the schedules studied in this investigation generated bursts of responding or chains of overt behavior between responses. Thus, neither of these phenomena is necessarily related to the development of temporal discriminations.

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