# Concurrent Activity Under Fixed-Interval Reinforcement

(WITH W. H. MORSE)

Under many schedules of reinforcement there are significant periods of time during which the organism does not display the behavior under investigation. For example, on a fixed-interval schedule there is commonly a period of no responding after reinforcement. The behavior which actually occurs at such times is apparently unrelated to any explicit reinforcement, yet the schedule is at least effective in controlling the time of its occurrence. Interesting examples are found in the field of psychotic behavior, where the patient engages in compulsive or other idiosyncratic ways only when he is not executing the behavior under the control of a given schedule. What the organism is doing when it is not showing the behavior produced by a schedule of reinforcement is especially important when we come to set up complex behavior in which two or more responses are studied at the same time.

## Method

Unreinforced behavior accompanying the performance generated by a common schedule of reinforcement was studied in the following way. A standard rat lever and food magazine were installed alongside the open face of an aluminum running wheel. The wheel was 13 in. in diameter, had a low moment of inertia, and turned in only one direction against friction which was just overcome by a tangential force of 30 gm. Through a gear-reduction and pulley system the rotation of the wheel advanced a pen across the moving paper tape of a modified cumulative recorder. Scales were chosen so that the commonest speed of running produced a slope in the neighborhood of 45°. Responses to the lever operated a standard cumulative recorder.

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Two rats were conditioned to respond to the operation of the magazine until they quickly seized and ate the .1-gm. pellet of food delivered. At this stage the wheel was immovable. After three sessions of magazine training all responses to the lever were reinforced for several sessions. A fixed-interval schedule was then put into effect, under which a reinforcement was set up every 5 min. (FI5) during a session of 3 hr. and 20 min. Both rats developed marked "scallops" during the first session, and the fixed-interval performance was allowed to develop during several sessions until the pause after reinforcement was well marked. At the beginning of the ninth experimental session on FI5 the wheel was unlocked. The rat could now respond to the lever or run in the wheel. (It could not do both at the same time because it faced away from the lever when running.) Because of its low inertia the wheel could be stopped and started instantly; hence a change could readily be made from one form of behavior to the other. Responses to the lever continued to be reinforced on FI5; no reinforcement was explicitly contingent upon running.

## Results

The first performance when the wheel was unlocked is shown for one rat in Fig. 1. Segments *A* and *A′* comprise a continuous record of the movement of the wheel. Segments *B* and *B′* show the concurrent activity on the lever. Reinforcements are marked by small hatches. Reinforcement *a* in Record *A* is the same event as that marked at *a* in Record *B*, and the same correspondence is maintained throughout the figure. It will be seen that the movable wheel occupies the rat for nearly 20 min. (beginning of Record *A*), during which no responses were made to the lever (beginning

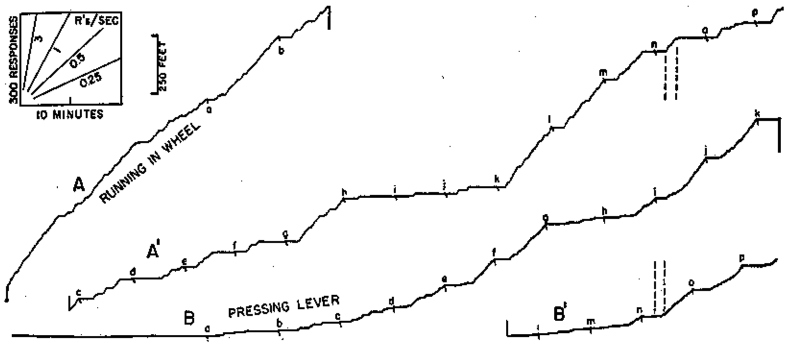

Fig. 1

of Record *B*). A first response to the lever is reinforced at *a*. The rat continues to show a high rate of running on the wheel between reinforcements *a* and *c* in Records *A* and *A'*, with corresponding low activity on the lever shown between reinforcements *a* and *c* in Record *B*. A few responses are made to the lever, however, and reinforcements are received approximately on schedule.

Before the end of the session the over-all rate of running has fallen off considerably (end of *A'*), and a fairly normal fixed-interval performance has been restored (end of *B'*). Running during each interval already begins to show a temporal pattern, which became consistent in later sessions. After reinforcement the rat neither runs nor presses the lever for a short period of time, which is much longer than the time required to eat the pellet of food. It then runs actively for distances of the order of 100 to 200 ft. before returning to the lever to resume a fairly standard-interval performance. After the reinforcement marked *n*, for example, a short horizontal section appears in both records. There is then a short burst of running in the wheel, marked by the vertical dotted lines in *A'*. The corresponding period in the lever record is indicated in *B'*. Running in the wheel ceases during the second half of the interval, when fairly constant responding on the lever is shown, leading to the reinforcement at *o*.

In order to obtain a collateral measure of the rate of unreinforced running, the following program was instituted. At the beginning of each session the rat had access to the wheel for approximately ½ hr., during which no responses to the lever were reinforced. A 6-w. lamp, previously used for general illumination in the apparatus, was off during this period, and responses to the lever were quickly extinguished in the absence of the light. The light was then turned on for 100 min., during which 20 responses were reinforced on FI5. The light was then turned off, and further running in the absence of responding to the lever was recorded.

The end of such a session for the rat in Fig. 1 is shown in Fig. 2. The curve at *B* shows the last five segments of the fixed-interval performance prevailing at this stage of the experiment. The segments at *A* and *A'* comprise a continuous record of the performance in the wheel during the five intervals and, beginning at *a*, after the light has been turned off and responding to the lever has ceased. Corresponding portions are connected by broken lines. The fixed-interval segments in *B* are now relatively "square" and suggest that responding is being postponed by the activity in the wheel. When pressing begins, however, a fairly stable, uniform rate is assumed until reinforcement. For a substantial period of time after each reinforcement, the lever is not pressed and running does not occur. Sustained running then takes place for 2 or 3 min., yielding to the behavior on the lever for the rest of the interval.

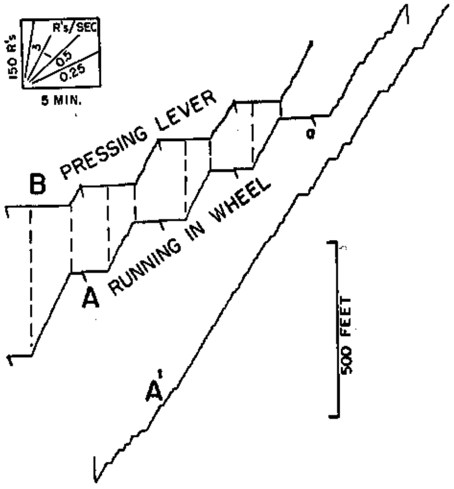

FIG. 2

The beginning of a daily session for the other rat at the same stage as Fig. 2 is shown in Fig. 3. Segment *A* and the first part of *A'* show the relatively fast spontaneous running in the absence of the light, when responses to the lever are not reinforced. When a first response is reinforced in the presence of the light at *a*, a performance appropriate to FI5 is begun (Record *B*). Note that, although there is little activity on the lever during

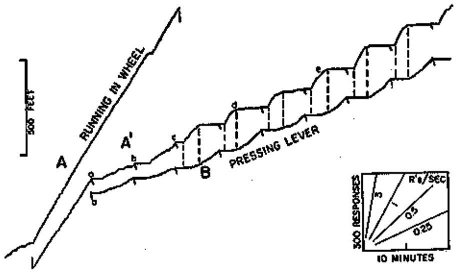

FIG. 3

the first two intervals, running in the wheel is greatly suppressed (compare the segments preceding *b* and *c* with Record *A*). A stable performance persists for the balance of the session, not all of which is shown in the figure. For a short period of time after reinforcement the rat does not respond to either lever or wheel. A burst of running then follows. This yields to responding to the lever in a somewhat more continuous fashion than in the case of the other rat. The rate of running falls off in a particularly smooth curve at *d* and *e*. The segments of Record *B* showing concurrent activity on the lever have a corresponding positive curvature which is absent in Fig. 2. A continuous change as in Fig. 3 was occasionally shown by the first rat, although the more rapid shift from wheel to lever seen in Fig. 2 was characteristic.

Since responding on the wheel falls off to zero or very nearly zero late in each interval, few if any adventitious reinforcements of running could occur as the result of quick shifts from wheel to lever. We may therefore suppose that activity in the wheel remains essentially unconditioned with respect to food reinforcement.

## Summary

When a rat is free to run in a low-inertia running wheel or to press a lever for food on a fixed-interval schedule, the resolution of the competition between running and pressing can be expressed in the following way. When the schedule normally generates a substantial rate of responding, running in the wheel is suppressed. When the schedule does not generate a substantial rate, running in the wheel occurs. Shortly after reinforcement, however, both behaviors are absent.

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# Sustained Performance During Very Long Experimental Sessions

(WITH W. H. MORSE)

Operant behavior is usually studied in experimental sessions separated by periods when the organism is not closely observed in its home cage. Even though technical advances are now available for maintaining responding for extended periods of time, the behavior under observation is seldom followed continuously 24 hours per day. The possibility of decrements in behavior (such as occur in "mental fatigue") prompted us to see just how long an animal could be kept responding in a continuous session.

The schedule of positive reinforcement best suited to maintain responding continuously is the differential reinforcement of very low rates. In the pigeon, this schedule can sustain behavior with a frequency of reinforcement below that required to maintain body weight.[1] The effect of sustained responding on several different performances can be observed by combining other schedules with the differential reinforcement of low rates in a multiple program, provided that reinforcement on these other schedules occurs infrequently enough to prevent satiation.

In the present experiment a multiple schedule was used which had the following components: a basic schedule, DRL, maintained responding at a fairly constant, low rate under the control of one key-color. Once every hour the color of the key changed to that designating another schedule, which was then in effect until reinforcement occurred. The other schedule was, alternately, either FR or FI. In this way, three different performances could be studied during continuous experimental sessions lasting many days or even weeks. The bird remained continuously in the experimental space,

From *Journal of the Experimental Analysis of Behavior*, 1958, *1*, 235–244.

[1] Herrnstein, R. J., and Morse, W. H. Some effects of response-independent positive reinforcement on maintained operant behavior, *J. Comp. Physiol. Psychol.*, 1957, *50*, 461–467.

and the over-all rate of reinforcement maintained the body weight, with only a slow drift toward satiation or a more extreme deprivation.

## Procedure

A standard pigeon box was modified to accommodate a considerable quantity of grain in the food hopper. The magazine presented grain for 5 seconds. Fresh water was supplied from the outside of the box through a tube. Two adult male White Carneau pigeons were magazine-trained, and all responses to the key were reinforced (*crf*) during three sessions for a total of 180 reinforcements per bird. The color of the key changed after each reinforcement to white, red, or green in random order. The birds were then run for 12 daily sessions lasting from 4 to 7 hours each on DRL 1 min. in the presence of the white key-light—that is, a response was reinforced only if it followed a period of 1 minute without a response. If a response occurred before 1 minute had elapsed since the previous response, the timer programming reinforcement was reset to zero, and the next response was reinforced only if it occurred after another minute or more had elapsed.

When a stable performance had developed on the DRL schedule, the multiple schedule was introduced. At 1-hour intervals the color of the key was changed from white (DRL) to either red or green: when it was red, the 50th response was reinforced (FR 50); when green, the first response after 10 minutes was reinforced (FI 10). After reinforcement on either the fixed-ratio or fixed-interval component, the key-color changed to white and the DRL schedule was again in effect. Three cumulative records were taken: one of the DRL performance (the recorder stopping when the other schedules were in force), one of the alternating FR and FI performances (the recorder stopping during DRL), and one of the DRL performance on a recorder with greatly reduced scales (one-twelfth the usual coordinates) to provide a short summarizing record of the whole experiment. When the multiple schedule was first introduced, each pigeon was run for several sessions approximately 3 days long. Later, the session was allowed to continue until the bird stopped responding because of satiation (or until the apparatus failed).

## Results

It was found that a pigeon could sustain a continuous performance indefinitely if precautions were taken to prevent satiation. During a long session

the fixed-interval performance of the multiple schedule occasionally showed unusual properties, and all three performances changed in expected directions if satiation occurred. Typical effects are shown in the cumulative records which follow.

### ACQUISITION OF THE DRL PERFORMANCE

In the transition to DRL from *crf* for Pigeon 162 (Fig. 1), a first response was preceded by a pause of more than 1 minute and was reinforced (at *a*). A pattern of responding typical of extinction then followed, as expected from the previous *crf*. A pause sufficiently long to meet the DRL requirement finally occurred, and a second response was reinforced (at *b*).

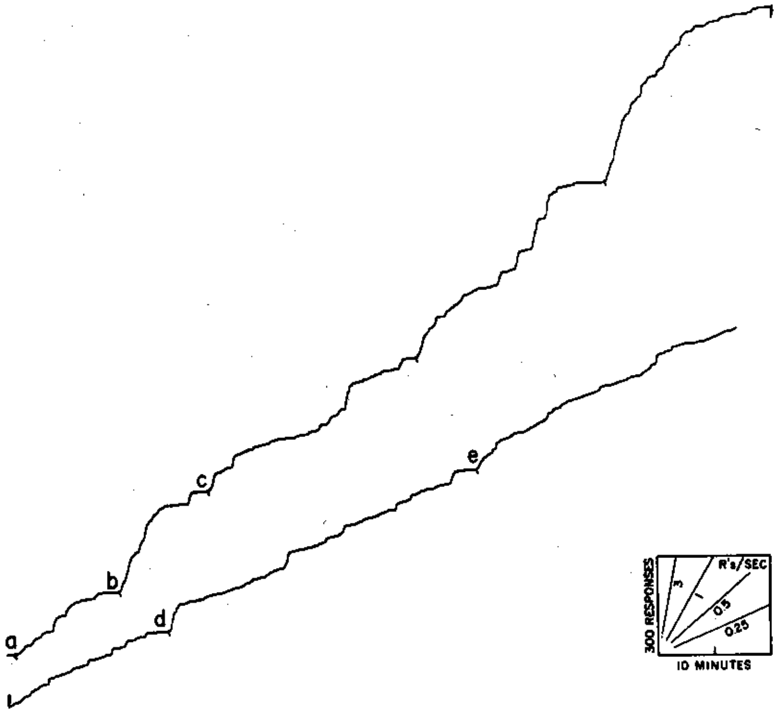

FIG. 1. Pigeon 162. Cumulative-response curve during the 1st session of DRL 1 minute after *crf*. See text for explanation of letters.

An extinction curve beginning at a higher rate followed, and the DRL contingency was again met at *c*. The over-all rate gradually fell to a fairly steady, low level, but occasional pauses were long enough to set up reinforcements, as at *d* and *e*. The latter part of the session is not shown.

The development of the 1-minute DRL performance for Pigeon 163 is shown in Fig. 2. Curve *B* is the summarizing record from the recorder with reduced scales. Records A and C, segments from the other DRL record, are located as indicated on Record B. The early performance of this bird is similar to the early stages of Fig. 1. By the end of the session the over-all rate has declined, but the requirement of a 1-minute pause is met only infrequently.

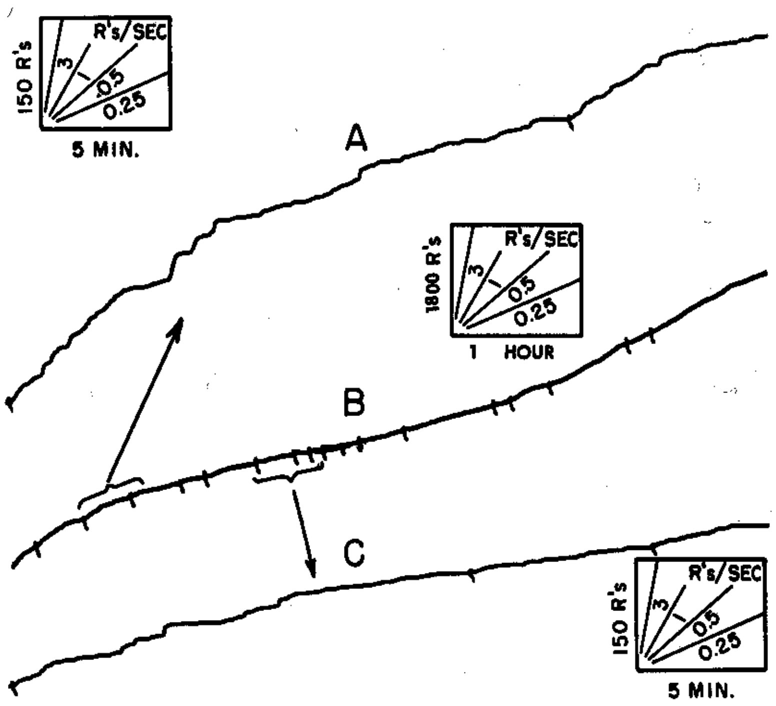

FIG. 2. Pigeon 163. Performance during 1st session of DRL 1 min. after *crf.* Records A and C are enlarged segments of Record B.

Further development of the DRL performance is shown in Fig. 3. Curve *A* is for Pigeon 163, Curve *B* is for Pigeon 162. Both curves are taken from the middle of the third session, approximately 10 hours after the beginning of DRL. Although the prevailing rate fluctuates, few pauses of greater than 1 minute occur. Curve *C*, shown on reduced coordinates, is the last DRL session for Pigeon 163. Note that the rate here is so uniformly sustained above 1 response per minute that only three reinforcements are received during the 5½-hour session. A rate of this order is needed for uninterrupted experimental sessions of the multiple schedule since 24 reinforcements will be received each day on the hourly ratio and interval components, and not more than an additional 10 reinforcements per day is needed to maintain the pigeon in the range of its experimental body weight.

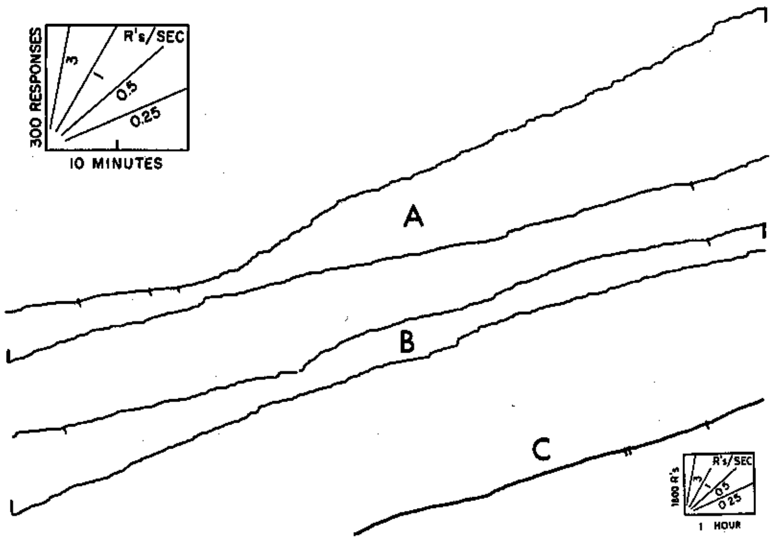

FIG. 3. Performance on DRL 1 min. Record A (Pigeon 163) and Record B (Pigeon 162) are from the middle of the third session. Record C (Pigeon 163) is the complete 12th session on DRL greatly reduced.

## PROLONGED PERFORMANCE DURING CONTINUOUS SESSIONS

The reduced summary record of the performance on the DRL component of the multiple schedule for Pigeon 162 during a single continuous session 154 hours long is shown in Fig. 4. This was the sixth long session

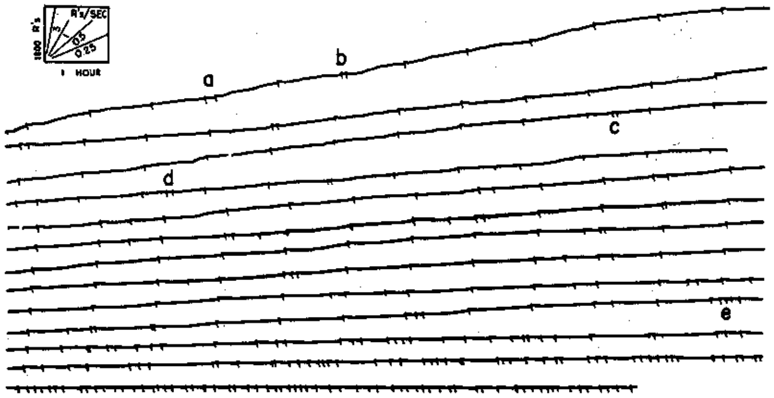

FIG. 4. Pigeon 162. Performance on DRL component of mult FI 10 FR 50 DRL 1 min. during 6th extended session (6½ days long).

for this bird, earlier sessions having been from 7 to 17 days long. (The summary record for the first long session for this bird has been published elsewhere.[2]) In Fig. 4 the recorder was stopped while the other schedules were in effect, but all reinforcements are shown. Those received on FR or FI can generally be identified because they occurred exactly 1 hour apart. It will be seen that only an occasional reinforcement is received on DRL. Reinforcements on DRL frequently occurred either after changing from the FR or FI schedule (as at *a* and *b*), or in pairs during the DRL component, as at *c* or *d*. (It is fairly characteristic of responding on DRL that reinforcements are received in pairs.)

In the session shown in Fig. 4 the rate fell because of an increase in body weight. Reinforcement occurred more frequently as satiation progressed because the DRL contingency was more frequently met. The last two lines of Fig. 4 show a frequency of reinforcement which produced such complete satiation that the experiment was stopped. Note that even when the over-all frequency of reinforcement is fairly high, reinforcements still tend to be grouped together, as at *e*.

During the long session shown in Fig. 4, performances on the fixed-ratio and fixed-interval components were recorded in a single cumulative curve. Record A of Fig. 5 shows the initial performance on the first day. The first interval shows no scalloping. A shallow scallop is characteristic of the start of the session on FI, but the present curve is unusually straight. This may be due in part to the fact that the bird had not been in the apparatus for 5 days (while the other bird had been studied). The shallow scalloping of later intervals in Fig. 5A may be partly due to the fact that the interval components are separated by 2 hours of other schedules. This fact may also have a bearing on the rather irregular performance shown in Record B (a segment beginning 45 hours after the start of the experiment) and Record C (beginning after 105 hours). Many of the intervals show a long pause followed by a high initial rate, as at *a* and *b*. "Knees" are common in Records A and B, and are seen later (as at *c*). In general, the terminal rate of the intervals is rather low and the curves are frequently negatively accelerated just before reinforcement. Some of this irregularity may be due to induction from DRL. In multiple schedules containing DRL components, superstitious "marking time" behavior is occasionally observed in other interval components. Occasionally, however, the more gradual increase in rate typical of fixed-interval reinforcement can be seen (as at *f*).

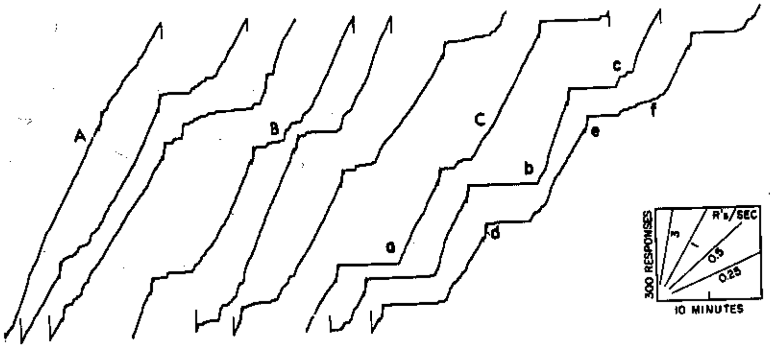

FIG. 5. Pigeon 162. Performance on FI and FR components of mult FI 10 FR 50 DRL 1 min. during 6th extended session. Record A begins after 1 hour, Record B after 45 hours, and Record C after 105 hours from the beginning of the experiment.

The fixed-ratio performance scarcely changed during the part of the session shown in Fig. 5. Slight pauses sometimes occur at the beginning of the ratio (as at *d* and *e*), but the terminal rate remains high throughout.

Both the fixed-ratio and fixed-interval performances change markedly toward the end of the long session. Figure 6, recorded immediately after Fig. 5C, shows the fixed-ratio and fixed-interval performances for more than a full day. Prolonged pauses now occur in interval components (as at *a*), and terminal rates in the intervals vary widely (compare intervals at

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[2] Skinner, B. F.; see page 132.

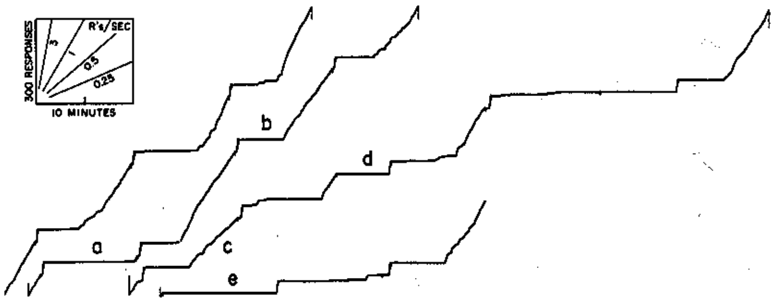

FIG. 6. Pigeon 162. Performance on FI and FR components of mult FI 10 FR 50 DRL 1 min. during 6th extended session. Record begins 125 hours after the beginning of the experiment.

*b* and *c*). The ratio performance frequently begins with a pause (as at *d* and *e*), but the rate remains high after responding has begun. The altered performance shown in Fig. 6 is presumably due to satiation; the record is similar to those obtained during progressive satiation on multiple fixed-ratio and fixed-interval schedules. The bird had begun the experiment weighing 390 grams (80% free-feeding weight) and weighed 440 grams (about 90%) when removed from the experimental box 7 days later.

Satiation can be prevented by changing the DRL value or by presenting the other schedules less frequently. In another extended session the bird shown in Fig. 4–6 responded for 28 days continuously. The value of DRL was varied between 3 and 4 minutes, as needed, to prevent extreme satiation or deprivation. During the first 2 days there was a slight increase in satiation and the bird paused for more than 10 minutes upon nine different occasions. During the next 6 days, however, no pause lasted for as long as 10 minutes. Subsequently, one pause of 11 minutes and one of 23 minutes appeared, but the bird did not pause for as long as 10 minutes during the next 6 days. Near the end of the experiment it again responded for 4 days with no pause longer than 12 minutes.

The fixed-ratio and fixed-interval performances during this 28-day session are sampled in Fig. 7 and 8. Figure 7A begins 56 hours after the start of the session. Occasional "knees" appear in the interval curves (as at *a* and *c*), and many intervals show the abrupt shift to a terminal rate following the initial pause (as at *b*). Sustained responding at a rate appropriate to the ratio component occurs at *d*, which is unusual in an ordinary multiple schedule. The ratio performance, meanwhile, shows a characteristic high rate with little or no pausing at the start.

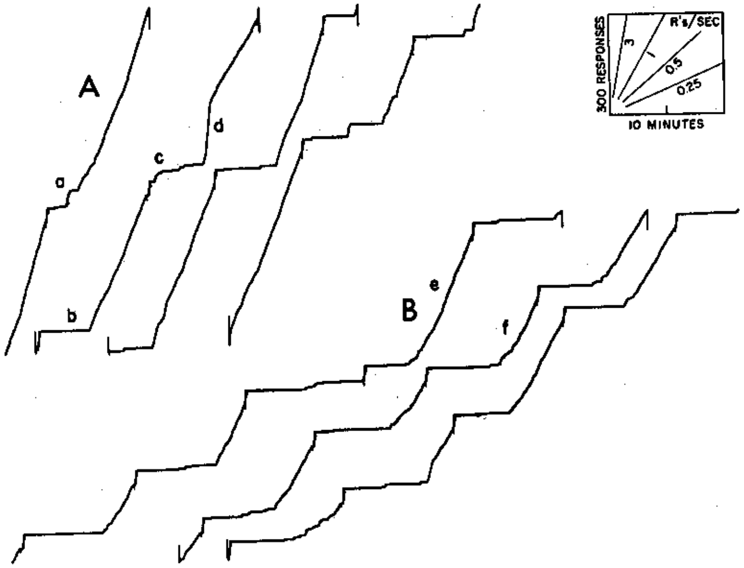

FIG. 7. Pigeon 162. Performance on FI and FR components of mult FI 10 FR 50 DRL 1 min. during 7th extended session (28 days long). Record A begins after 56 hours, and Record B after 264 hours.

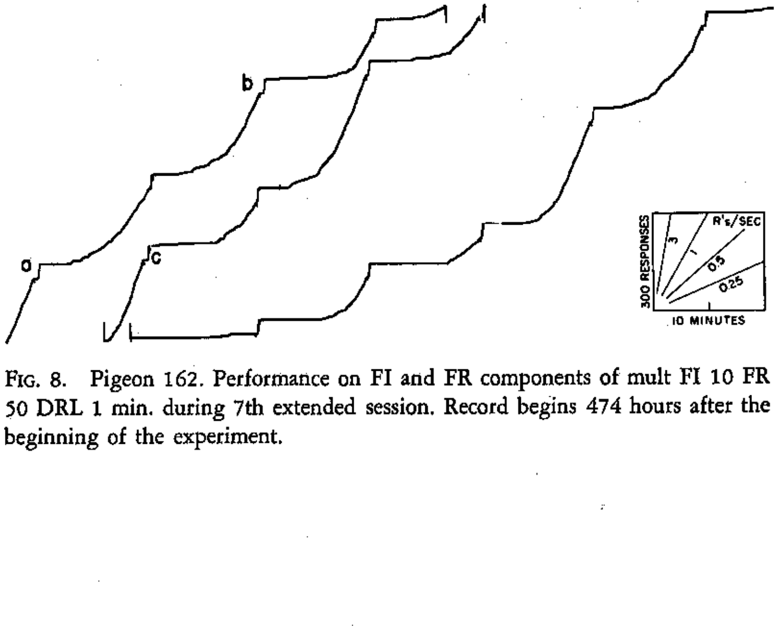

FIG. 8. Pigeon 162. Performance on FI and FR components of mult FI 10 FR 50 DRL 1 min. during 7th extended session. Record begins 474 hours after the beginning of the experiment.

Figure 7B was recorded after 264 hours. Although prolonged pauses and abrupt shifts to a moderate terminal rate still appear, some fairly characteristic interval curves may be seen (as at *e* and *f*). A series of reasonably normal interval scallops appear later in the session, as shown in Fig. 8, which begins after 474 hours of continuous responding. Both the interval and ratio performances are normal except for an occasional slight pause at the beginning of the ratio, as at *a, b,* and *c.* The performance in Fig. 8 shows little or no effect of the intervening hours on DRL or of sustained responding for almost 500 hours.

The other subject, Pigeon 163, showed more marked irregularities on the other components of the multiple schedule. Figure 9A, from the beginning of an extended session, shows a relatively low rate on the ratio component, but a fairly good scallop on the interval component. The ratio rate is still low in Fig. 9B, 175 hours later, although it is now usually higher than the terminal rate in many of the intervals. "Knees" are common, as at *b,* and the interval curves tend to show negative acceleration, as at *a* and *c.* At this time the bird was responding at a steady sustained rate on DRL.

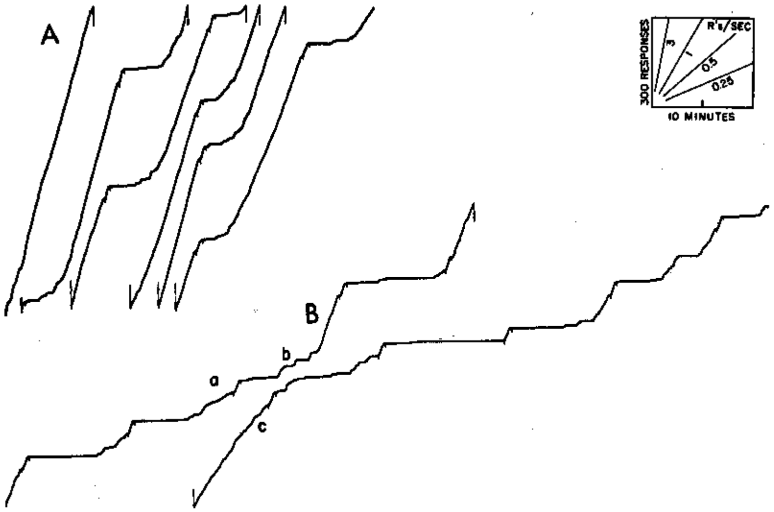

FIG. 9. Pigeon 163. Performance on FI and FR components of mult FI 10 FR 50 DRL 1 min. during 2nd extended session (24 days long). Record A begins 1 hour, and Record B 175 hours after the beginning of the session.

During another long session with Pigeon 163, the DRL rate was so consistently above that required for reinforcement that at one point in the experiment no reinforcement was received on DRL for over 31 hours. In other words, the pigeon never paused for as long as 3 minutes during that period. The sustained performance on the DRL component must have been due at least in part to induction from the intervening FR and FI components; no comparable performance has ever been observed on a simple DRL schedule. As with the other bird, however, induction was observed in the other direction. Figure 10 shows the FR and FI performances beginning 984 hours after the start of the session. In general, the ratio performances are typical, and many of the interval curves are also fairly normal. A series of interval segments, however (at *a, b,* and *c,* and again at *d* and *e*), shows a drop to a low rate during the interval. This suggests interference from the DRL.

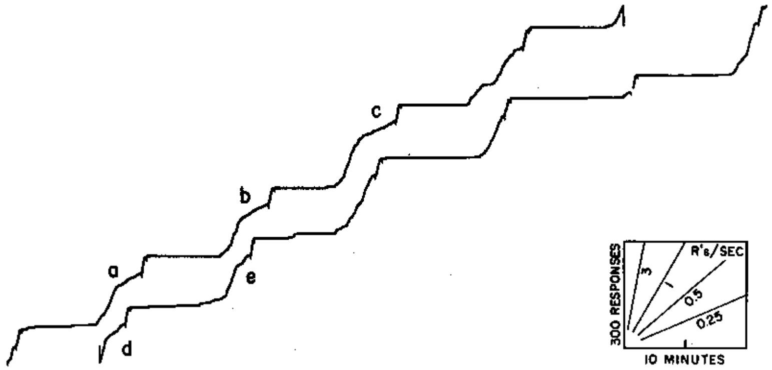

FIG. 10. Pigeon 163. Performance on FI and FR components of mult FI 10 FR 50 DRL 1 min. during the 3rd extended session (65 days long). Record begins 984 hours after the beginning of the session.

## Summary

The behavior of pigeons has been studied continuously for sessions of many days or weeks by using a multiple schedule in which slow but continuous responding is maintained with few reinforcements on DRL, while FI and FR schedules alternate at hourly intervals. To a remarkable degree the performance on the ratio and interval components after hundreds of hours resembles that obtained using a conventional daily session. The major deviations in the ratio and interval performance during these long sessions are mostly attributable either to changes in deprivation or to a slight failure in stimulus control. Possible induction from DRL to FI is occasionally shown by a low rate in FI. Induction from FR to FI may explain an occasional unusually high rate in FI. Induction from both FR and FI components appears to sustain performance for many hours on DRL without reinforcement on that schedule, although "superstitious" reinforcements from the change to other key-colors may also be relevant. The combined schedule provides a base line of continuous responding which should be useful in studying the effects of physiological, pharmacological, or other variables acting over long periods of time.

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# John Broadus Watson, Behaviorist

John Broadus Watson, self-styled "the behaviorist," died on 25 September 1958 at the age of 80. His scientific life had come to a close a third of a century earlier, and he was unknown personally to a whole generation of younger men whose field of scientific activity he had defined and vigorously developed. His place in the history of science, and something of his stature, are indicated by three names—Darwin, Lloyd Morgan, and Watson—which represent three critical changes in our conception of behavior.

In establishing the continuity of species Darwin had attributed mental processes to lower organisms. He was supported by a host of anecdotal naturalists who recounted instances of reasoning, sympathy, and even artistic enjoyment on the parts of dogs, cats, elephants, and so on. The inevitable reaction was epitomized in the writings of Lloyd Morgan, who argued that such evidences of mental processes could be explained in other ways. A third step was inevitable, and it was Watson who took it: If there were other explanations of mental processes in lower organisms, why not also in man?

In dispensing with mentalistic explanations of behavior, Watson cleared the way for a scientific analysis. In doing so he acknowledged his debt both to Lloyd Morgan and to Thorndike, who, though he remained a mentalist, supplied a classical alternative explanation of "reasoning" in his experiments on trial-and-error learning. The epistemological issue was also in the air. Watson never took to philosophy (though, as he later said, his "milk teeth were cut on metaphysics"), but it was George Herbert Mead's great personal interest in Watson's animal experiments which supplied an immediate and crucial contact with relevant philosophical issues. A behavioristic interpretation of mental processes was later adopted by operationists and logical positivists, but the issue was to remain primarily empirical rather than logical.

From *Science,* 1959, *129,* 197–198.