STUDIES ON BEHAVIOR. I. DIFFERENTIAL SENSITIVITY TO PENTOBARBITAL OF PECKING PERFORMANCE IN PIGEONS DEPENDING ON THE SCHEDULE OF REWARD[1, 2]

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The use of experimental animals in the analysis of behavioral effects of drugs has been hampered by a paucity of objective, quantitative methods of study. However, the techniques developed by Skinner and his colleagues permit a strictly operational approach to these problems (Skinner, 1953; Ferster, 1953). The animal is confronted with a device which it can operate; the "response" of the animal is defined as such an operation. The animal is suitably rewarded for responding. Rewards can be made intermittent, i.e. not every response need be rewarded. The rate of response at different times depends upon the contingencies which determine which response will be rewarded (see below). These contingencies can be specified and responses are automatically recorded; so the methods are both objective and quantitative.

As long ago as 1937, Skinner and Heron studied the effects of caffeine and of amphetamine on the performance of rats working in a Skinner box. The following year, Wentink (1938) reported on the effects of a variety of other drugs. In spite of the interesting results obtained, the studies were not continued. Recently, Wikler (1954) has presented a preliminary communication on use of the Skinner box technique to study the effects of morphine on "behavior-disrupting anticipatory responses to painful stimuli" in rats.

In the present work, the experimental animals have been pigeons. The birds were confronted with a device (the key), which was operated by a peck. Reward was access to food; this was rewarding because the birds were maintained in a state of partial food deprivation.

To show promise of usefulness for the analysis of behavioral effects of drugs a method should enable a behavioral effect to be detected and measured following doses insufficient to cause gross disturbance of the animal. The principal object of the present communication is to present the Skinner box technique as a method of potential usefulness to pharmacologists, and to give evidence that the above requirement for promise is met. The drug chosen was pentobarbital sodium because its duration of action was convenient.

MATERIALS AND METHODS.[3] *Apparatus.* In all the studies reported here, the same Skinner pigeon box has been used; its general arrangement is shown in figure 1 (not to scale). The

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[2] A preliminary report appears in This Journal, **110:** 14, 1954.

[3] For a more detailed account of the principles involved in the design of the apparatus see Ferster (1953).

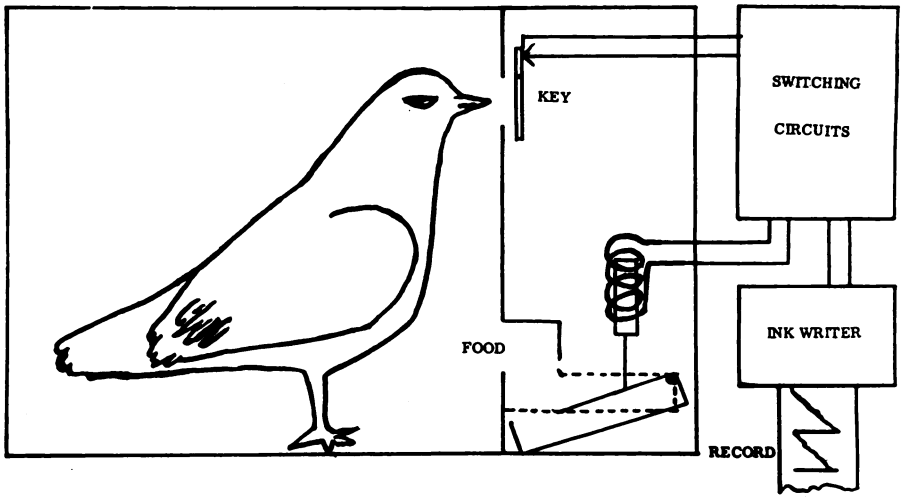

DIAGRAM OF SKINNER PIGEON BOX

FIG. 1. *Diagram. Skinner pigeon box.* (Not to scale.) For details see text

pigeon is placed in a soundproofed ventilated box. The key is a recessed disc of light translucent plastic in one wall, at a convenient height for the pigeon to peck. When the pigeon pecks it, an electrical contact is broken. On release, a spring restores the key to its original position and so remakes the circuit. The maximum permitted excursion of the key is only a few millimeters, and the strength of the spring is such that the cycle of make and break of the key circuit can be repeated at least 10–15 times per second. Behind the key is a small (6W) electric bulb (the key light).

A tray of food can be lifted by an electromagnet so that it is accessible to the pigeon through an opening in the pigeon chamber below the key. At each reward, the food is made accessible, and brightly illuminated, for 4–5 seconds. The rest of the time, the food is out of reach of the pigeon.

The electrical connections from the box lead to an arrangement of simple switching, timing and counting devices which automatically program the schedules to be described.

Responses were recorded on a Gerbrands' cumulative recorder.[4] Paper feeds through the recorder at constant speed; each response moves an ink pen a constant distance at right angles to the direction of movement of the paper. After approximately 900 responses, the pen resets automatically. The records have thus time as abscissa and cumulative responses as ordinate; the slope of the curve gives the rate of response. Also, occurrence of rewards can be shown on the records. In addition, responses can be counted with digital counters.

SCHEDULES. (See figure 2.) (1) *Fixed ratio of responses to rewards.* The bird was put into the completely darkened box. Fifteen minutes later, the key light came on and remained on for five minutes. During this five minute period, every 50th response was rewarded. At its conclusion, the bird was removed from the box, the drug injected, and the bird returned to the box. Fifteen minutes later, the key light came on again, and remained on for fifteen minutes, during which time, again, every 50th response was rewarded. This schedule will be referred to as FR50. On this schedule, the higher the rate of response, the sooner a reward was obtained.

(2) *Fifteen minute fixed interval.* The key light came on fifteen minutes after the bird was placed into the darkened box. The first response made after the key light had been on for

[4] Made by Mr. Ralph Gerbrands, 96 Ronald Road, Arlington, Massachusetts.

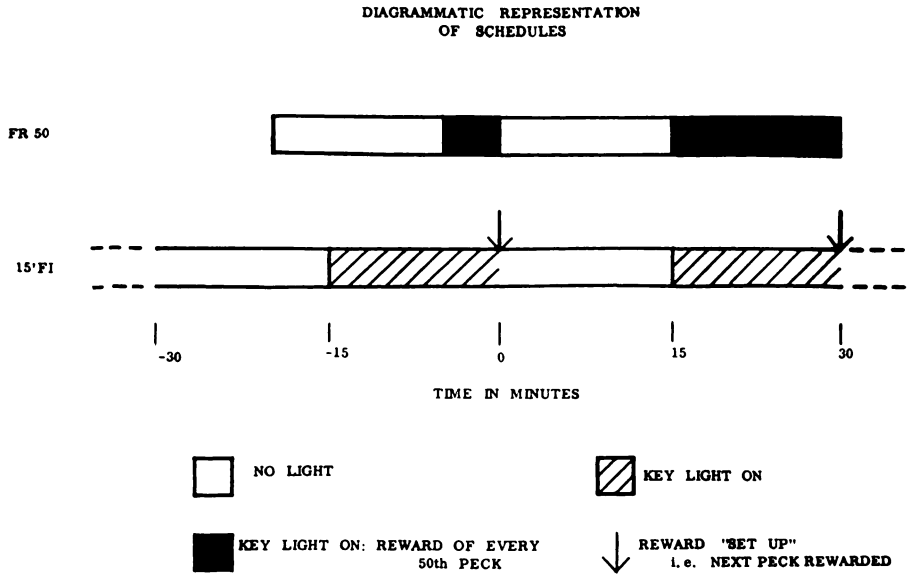

FIG. 2. *Diagram showing the sequence of events in definitive experiments on the two schedules.* The drug injection was given at time 0. On the 15'FI several light on-light off cycles were run both before and after drug.

fifteen minutes (the "fixed interval") was rewarded. Responses occurring before the end of the fixed interval were not rewarded; the key light remained on after the end of the fixed interval until the first response occurred. At the time of the reward, the key light went out and remained out for fifteen minutes; it then came on again and the whole cycle was repeated. After three or four such repetitions, the drug was administered immediately following a reward. Hence, as on fixed ratio schedule, the key light came on fifteen minutes after drug administration, and so the subsequent fifteen minute sample of behavior was comparable in its time relations to drug administration to the fifteen minute post-drug period studied on FR50. Usually, the bird was allowed to remain in the box through several cycles following the drug. This schedule will be referred to as 15'FI. On this schedule, rate of response during the fixed interval had no effect on the time of reward.

Sources of error. In the experiments on the ratio schedule, the pecks were counted with Veeder Root digital counters, which were able to follow considerably higher rates than the maximum pecking rate encountered in these experiments (2/sec) and are, therefore, virtually errorless. In the interval schedule experiments, the numbers of pecks were estimated by measurements of the ink record; the measurements were subject to an average error not exceeding 3 per cent. Periods of time on both schedules were timed with Eagle Signal Corporation Timoflex Timers and were subject to a random error not exceeding 1.5 per cent. Errors arising from these sources will be included in the empirical estimates of errors given in the results section. A systematic source of error not so included arose from the error of adjustment of the timers to the specified intervals; this did not exceed 10 seconds. The cumulative systematic error resulting from comparison of rates over periods timed by different timers (as in the ratio experiments) does not exceed 5 per cent.

Animals. Male white pigeons, not less than two years old, and weighing between 400 and 500 grams have been used. Throughout the experiments each pigeon was kept close to a running weight, which was approximately 80 per cent of the weight it attained when given free access to food. At the same time each day, and after the experimental run, the bird was

weighed, and fed a weight of grain equal to the difference between its running weight and the weight at the time of weighing.

Training. The hungry bird was placed in the box and, without closing the top, the food tray was raised and kept up until the bird ate from it. After allowing the bird to eat for a few seconds the food tray was lowered and the procedure repeated 10–20 times at irregular intervals until the bird approached and started eating from the tray immediately after it was raised. The food tray was then automatically raised for the usual reward time (4–5 seconds) at irregular intervals of from a few seconds up to thirty minutes. This procedure was continued until the bird not only ate from the tray immediately after it was raised, but did not attempt to get at the food when the tray was lowered and not illuminated. At least 100 rewards were given in this way. Then a grain of wheat was stuck on the key under a small piece of transparent adhesive tape and the key transilluminated. The circuits were arranged so that each peck of the key caused the food tray to rise. Sooner or later, usually within a few minutes, the bird would peck at the grain of wheat, and so obtain a reward. After remarkably few repetitions—often as few as 2 or 3, rarely more than 5—the bird came to peck the key immediately after the food tray descended. The grain of wheat could be removed from the key at this stage. After about 100 individual pecks had been rewarded, training on the appropriate schedule was started. The above training procedure was conducted in a series of sessions, individual sessions often being separated by several days. During training on the schedules, and through the subsequent experimental period, the birds had a single daily session in the box, except, usually, on Sundays.

Procedure. Two pigeons were run on FR50 and two on 15′FI. Each bird was given, in random order, a series of graded doses of pentobarbital, each dose and saline alone being given once only. The schedules were then crossed over; the pigeons working on FR50 were put on 15′FI and *vice versa*. After the birds had worked for 1 to 2 weeks on the new schedule, the series of doses of pentobarbital was repeated. The basic information obtained is of the effect of 5 doses of pentobarbital and one of saline in each of 4 pigeons and on each of 2 schedules; 24 experiments in all.

Pentobarbital sodium was dissolved in 0.9 per cent sodium chloride solution and injected intramuscularly. Dosages are given in terms of the sodium salt and give the total dose administered.

Gross effects of the drug were studied by placing the pigeon after dosing in a large open glass jar, and observing throughout the time of drug effect.

RESULTS. *Effect of schedule.* As reported by Skinner and his colleagues (see e.g., Skinner, 1953), the response rates were markedly affected by the schedule of reward. A comparison of the average rate of pecking in the control (before drug) period of four birds, when they were working on FR50 and when they were working on 15′FI is shown in table 1. Response rates were much higher on

TABLE 1

Mean response rates (pecks per minute) during the control period on six days

Pigeon No.	Schedule			
	15′FI		FR50	
	Mean rate	S.D.	Mean rate	S.D.
1	27	8.2	130	7.2
2	14	3.8	90	14.5
3	23	9.4	86	19.8
4	31	15.9	111	24.9
Grand mean.....	24		104	

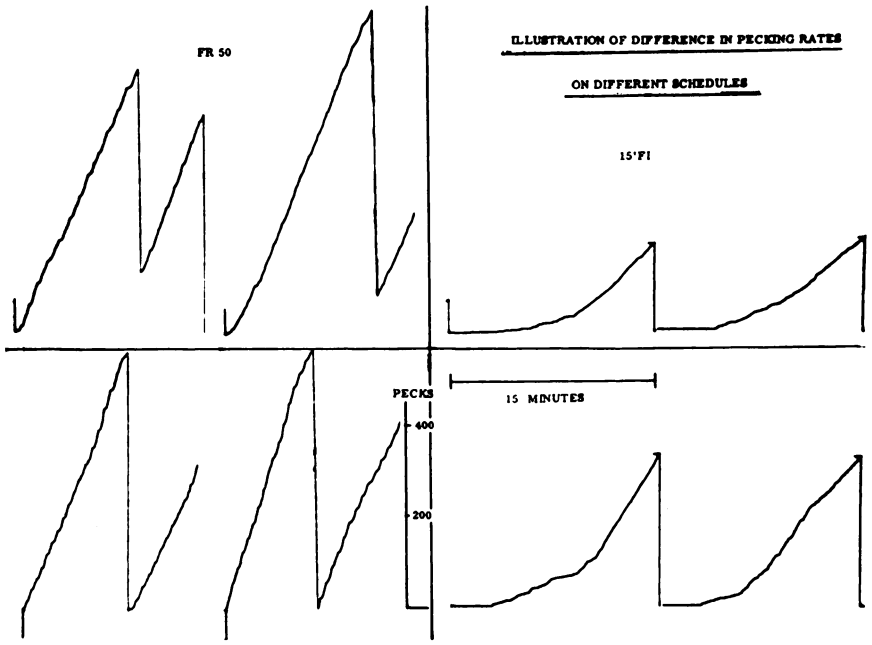

FIG. 3. *Pecking rates of pigeons on different schedules.* Typical records, two birds working on FR50 (on left) and on 15'FI (on right). For each schedule, two control periods of fifteen minutes are shown. On the 15'FI records the time of reward is shown by the short horizontal mark at the end of each period. Rewards are not shown on the FR50 records.

FR50. The lowest mean rate among the four birds when working on FR50 was more than twice as great as the highest mean rate when working on 15'FI.

The standard deviations give an estimate of the variation from day to day in the mean rates; 15'FI gave much less stable performance in this regard (mean coefficient of variation 37 per cent) than did FR50 (mean coefficient of variation 17 per cent).

Another difference between the performances on the two schedules is illustrated in figure 3. It shows typical records for each of two birds working successively on FR50 and 15'FI. On FR50 the rate of response was constant throughout the fifteen minute period of observation. In contrast, on 15'FI the rate of response showed a progressive increase through the fifteen minute period, giving the records of each individual interval an upward concavity.

It should be emphasized that the only change in the apparatus made as between the two schedules was a change in the switching circuits determining the schedule of reward. All features of the box proper, and so all constant features of the environment observable by the pigeon were identical on the two schedules. Hence, the difference between the high constant rate of response on FR50 and the generally lower, but accelerating, rate of response on 15'FI must be attributed to the difference in the schedule of reward.

Effects of pentobarbital. The gross effects of various doses of pentobarbital sodium are summarized in table 2; a dose of more than 2 mgm. was necessary to cause unequivocally observable effects.

TABLE 2

Directly observable effects of pentobarbital sodium on pigeons

Dose of Pentobarbital Sodium (i. m.)	Grossly Observable Effects
mgm.	
5.6	Loss of righting reflexes within 5 minutes of injection, but eyes remained open and pigeons appeared "aware" of surroundings. Apparent recovery in 20–30 minutes
4	Marked inco-ordination of movements and weakness within 10 minutes of injection. Apparent recovery in 20 minutes
2	No gross effects. Birds able to run without apparent inco-ordination. Suggestion of reduced "aggressiveness" in a bird well known to the observer, but effect not apparent to observer not familiar with bird
1	No effect apparent in any of the birds

The effects of pentobarbital sodium on performance in the Skinner box are summarized in figure 4. The drug effect (ordinate) was estimated as the ratio of the mean rate of response after the drug to the mean rate of response before the drug on the same day. These ratios were averaged over the four birds to give the points shown. This method of expressing the drug effect eliminates variability due to day to day changes in overall mean rate but includes that due to the difference between the birds in their sensitivity to pentobarbital.

The mean of the ratios of experiments in which no injection was given was 0.94 (S.E. 0.037) for FR50 and 0.92 (S.E. 0.110) for 15'FI. Each of these figures is based on 20 experiments. When saline alone was injected the mean ratios were 0.84 (S.E. 0.040) for FR50 and 0.57 (S.E. 0.065) for 15'FI. There is thus evidence that handling the birds and injecting saline has an appreciable effect on subsequent performance.

The much greater sensitivity to depression by pentobarbital of performance on 15'FI than that on FR50 is shown in figures 4 and 5. For example, compared to saline alone, 1 mgm. of pentobarbital caused a significant ("t" = 3.5, d.f.6, $P < .02$) decrease in the mean ratio of the birds when working on 15'FI but an increase in the mean ratio when the birds were working on FR50. The difference in the dosage of pentobarbital necessary to depress the response rate depending on the schedule of reward, is shown again by the estimated ED50 values (table 3). The ED50 was defined as the dosage of pentobarbital necessary to cause a reduction in mean response rate to 50 per cent of its value before the drug. It was estimated by linear interpolation on the log dose effect curve.

The individual interval records of birds working on 15'FI not under the influence of a drug, showed overall upward concavity with extreme regularity (figures 3 and 5). After small doses of pentobarbital, and during the recovery phase from larger doses, there was a marked tendency for the concavity to be lost; sometimes the records showed an upward convexity, an appearance never seen in the records of normal birds except in the initial stages of training.

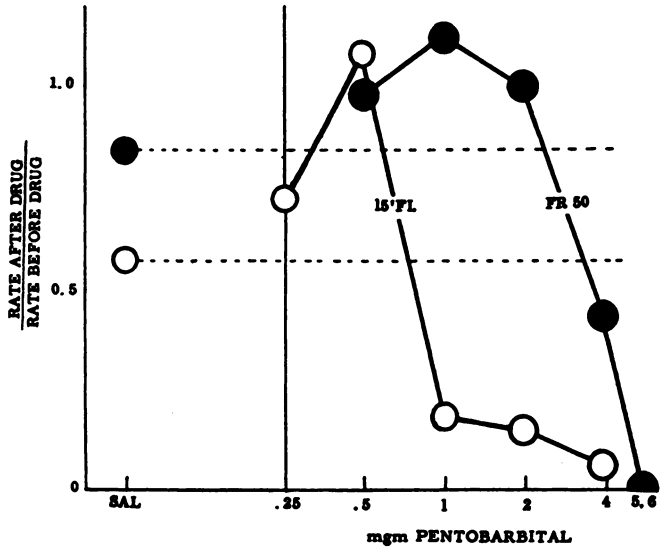

FIG. 4. *Effect of pentobarbital on pecking behavior of pigeons.* Log dose-effect curves. Each point represents the arithmetic mean of the ratios for the same four birds at each dosage level on each schedule. Open circles: mean effects, birds working on 15'FI. Solid circles: birds working on FR50.

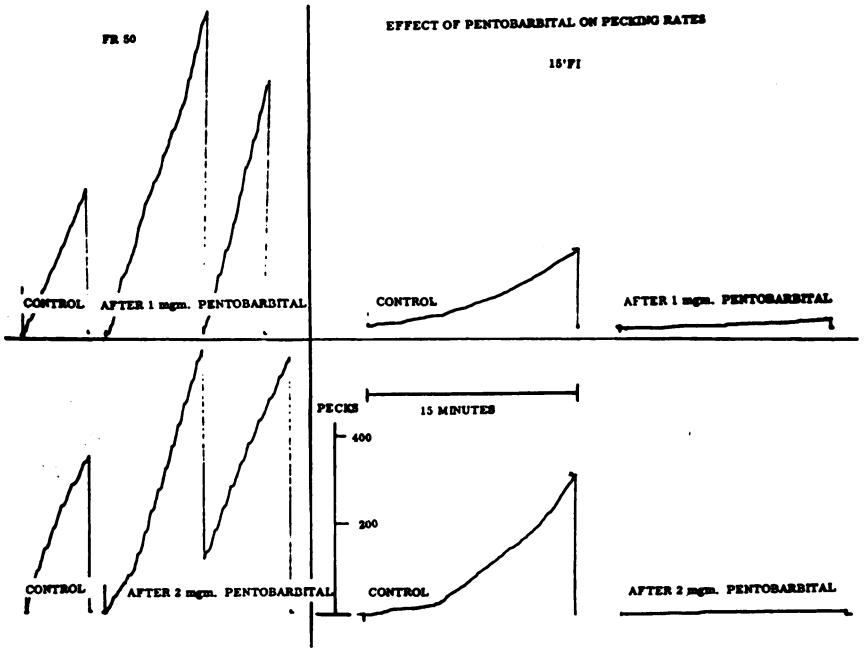

FIG. 5. *Differential effect of pentobarbital on pecking performance depending on schedule of reward.* On the left, records from two pigeons working on FR50 showing a five minute control run before drug and then a fifteen minute run starting fifteen minutes after drug administration. On the right, records from the same two birds working on 15'FI showing an interval record before the drug, and then the record of the interval which started fifteen minutes after drug administration.

TABLE 3

Differential sensitivity of response rates to depression by pentobarbital according to schedule

Pigeon No.	E. D. 50 Pentobarbital (mgm.)	
	15'FI	FR50
1	0.78	3.3
2	0.68	4.0
3	0.85	4.9
4	0.50	3.0

DISCUSSION. The pecking performance of pigeons working in a Skinner box on 15'FI schedule was significantly affected by a dose of 1 mgm. pentobarbital sodium. This dose caused no change in the behavior of the birds detectable by simple observation; even after twice the dose (2 mgm.) the directly observable effects were so slight as to be equivocal. Hence use of the Skinner box technique permits the effect of a drug on a behavioral activity of an animal to be detected and measured following a dose insufficient to cause gross disturbance of the animal.

Following doses of 1 or 2 mgm. to birds working on FR50 the rate of response was, on the average, higher than following saline alone. Clearly, these doses of pentobarbital do not interfere with the pigeon's physical ability to execute the response at a high rate. Yet these same doses caused marked reductions in response rates when the same pigeons were working on 15'FI. The use of the two schedules has thus permitted the effect in performance on 15'FI of doses of pentobarbital in the range 1 to 2 mgm. to be identified as an effect on the "higher" central nervous processes determining rate of response, and not as an effect on the physical capacity of the pigeon to peck the key rapidly such as would result, for example, from gross inco-ordination or weakness. When the pigeons were working on FR50 they maintained a constant rate of response throughout the period when the key light was on. On the other hand, on 15'FI the response rate progressively increased through the interval, although all environmental stimuli remained constant. Thus the response rate on 15'FI must be determined by factors additional to simple physical environmental stimuli. The greater sensitivity to modification of performance on 15'FI by small doses of pentobarbital suggests that it is the control of rate of response by these additional factors which is more easily disrupted by pentobarbital.

It is interesting to note that, for each schedule, a dosage of pentobarbital was found which led to an increase in average rate of response; this might properly be considered a behavioral stimulating effect.

SUMMARY

Pigeons working in a Skinner box developed different rates of pecking depending on the schedule of reward.

When every 50th peck was rewarded (FR50) the rate of response was high and constant.

When the first peck after an interval of fifteen minutes was rewarded (15'FI) the average rate of pecking was low and there was a steady increase in rate through the interval.

Pecking of the birds on 15'FI was markedly reduced by doses of pentobarbital which had no effect, or caused an increase in rate of pecking of the same birds working on FR50. This differential sensitivity to depression by pentobarbital of performance on different schedules shows that by use of these techniques a behavioral effect of a drug can be detected and measured under circumstances when the drug does not affect the physical ability of the pigeon to execute a peck.

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