*THE EFFECT OF DEPRIVATION AND FREQUENCY
OF REINFORCEMENT ON VARIABLE-
INTERVAL RESPONDING¹*

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Investigations to analyze the effects of deprivation and reinforcement variables upon operant behavior generally take one of two forms. Either *stable states* of operant strength developed under some schedule of reinforcement are observed under different deprivation conditions, or a *change in state* produced by altering a reinforcing contingency is recorded at several deprivation levels. The first class of operations has often been called the study of "drive and performance," the second class the study of "drive and learning." A stable state, however, is a special case of a class of changes; the important difference between the two cases lies in the conditions manipulated, and, hence, in the controls required rather than in the datum under observation. The same dependent variable, rate of emission, is measured, and both designs address themselves to a single analytical problem—that of developing a general quantitative description *relating the effects* of deprivation and reinforcement conditions.

The present experiment approaches this problem in terms of the first procedure. A stable rate of emission is established by an appropriate schedule of reinforcement. The rate of responding is then observed under several deprivation conditions, and a similar procedure is carried out with several schedules which differ in frequency of reinforcement. This design is adopted because the requisite control over the effects of a reinforcer delivered repeatedly to more than one organism is most readily demonstrated where these effects do not undergo an appreciable change during a single observation period.

Previous experiments involving similar procedures have shown that while ratio behavior is relatively insensitive to moderate deprivation changes (4), interval behavior is affected both by deprivation level (2, 5, 8) and by interval size or frequency of reinforcement (5, 12). Sensitivity to these conditions has led to the use of interval schedules for calibration purposes, both where animals are selected to yield a constant behavioral effect under the same deprivation conditions (7), and where the deprivation manipulations are adjusted to yield a constant effect on unselected organisms (6). Although some recent evidence indicates that considerable resistance to rate changes may be produced under interval schedules (2), it is uncertain whether this finding is attributable to particular deprivation operations, or simply to the hysteresis-producing effect of a long history of responding at a relatively constant rate.

Interval schedules are used in the present experiment because of their demonstrated sensitivity to both independent variables. Variable-interval (VI) rather than fixed-interval (FI) schedules are chosen in order to avoid the differential effects of discriminative stimuli associated with the passage of time (9). In addition, the par-

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ticular average inter-reinforcement intervals together with the lengths of observation sessions are selected so as to minimize differences in the effects of the passage of time and the consumption of food within experimental sessions.

SUBJECTS

Nine male albino rats of a mixed strain were divided into three groups. Group A received training on a 1-minute VI schedule, Group B on a 2-minute VI, and Group C on a 3-minute VI. At the beginning of preliminary training, Ss were approximately 130 days old and ranged from 343 to 383 grams in free-feeding weight.

APPARATUS

A Skinner box was used, with lever, food tray, and water bottle at one end. The lever was 1/2 inch thick, 2-1/8 inches long, and was centered with its top edge 3-1/2 inches from the floor. A force of about 20 grams was required to close the switch attached to the lever. Reinforcements were 0.045-gram food pellets delivered by a Williams rotary feeder. The experimental cage with lever and feeder fitted into a larger, sound-deadened box containing interior lights and an exhaust fan. A window in the top of the larger box permitted observation of the interior. This apparatus was located in an air-conditioned room maintained between 75 and 78 degrees Fahrenheit. Recording and control apparatus was located in an adjoining room. Responses and reinforcements were recorded on a Gerbrands cumulative recorder.

PROCEDURE

Before being placed on their respective VI schedules, all animals were deprived, exposed to the experimental situation, feeder-trained, and bar-trained. Each animal was then given a session consisting of 20 successive reinforced lever depressions, followed by 1 hour of extinction. This extinction period provided an opportunity for the emission of any approximations or superstitions reinforced during bar training, and was found to increase the uniformity of topographies established during acquisition of the VI schedules. After extinction, each group of three animals received 360 reinforcements under one of the VI schedules. This training was given in six daily sessions of 60 reinforcements each, preliminary experiments having shown that little change in individual topography, grain, or average rate could be expected between 200 and 600 to 700 reinforcements. The three schedules were composed of self-repeating sequences of the following intervals (in seconds): 1-minute VI—15, 40, 80, 3, 110, 50, 118, 20, 105, 115, 5, 100, 30, 10, 60, 90, 70; 2-minute VI—100, 5, 15, 140, 40, 200, 230, 3, 160, 120, 20, 80, 220, 237, 10, 180, 60, 110, 235, 130, 225; 3-minute VI—10, 30, 240, 120, 360, 60, 420, 180, 20, 300, 240, 90, 400, 180, 300, 60, 30, 240, 120, 180, 20, 360.

Throughout the experiment, each animal was fed daily an amount of dry food equal to 80% of the difference between his observed weight and 80% of his free-feeding weight. The ration (ground Purina dog chow) was made available for 1 hour at the same time each day. This method of controlling daily hunger cycle is modified from one used previously by Dinsmoor (1), and insures a relatively constant

percentage of free-feeding weight immediately after feeding each day. In the present case, weights immediately after eating remained at slightly less than 85% of free feeding after the first 10 days under the feeding schedule. The deprivation program was in effect throughout preliminary training, and had been in force for 21 days at the time of the first experimental observation.

After the Ss had adjusted to the deprivation program and had acquired the above reinforcement history, the experiment proper was begun. The rate of responding of each animal was measured at seven different times during the daily hunger cycle, but each animal was kept on the same schedule throughout. Daily observation periods were 20 minutes for Group A (1-minute VI) and 30 minutes for Groups B and C (2-minute and 3-minute VI). (A longer period was required in the latter cases in order to remove the effects of introducing Ss into the apparatus.) One observation per animal was made daily for 21 days, with each S observed for three consecutive days at each of seven deprivation times (1, 3, 5, 7, 10, 20, and 23 hours after the beginning of the daily feeding hour). In order to counterbalance the possible effects of the order of deprivation times, one S in each group was run through this sequence in ascending order, one in descending order, and one in a mixed order. In all cases, however, the three daily observations at each deprivation time were made consecutively.

RESULTS

Figure 1 gives the mean rate of responding for each deprivation time under each schedule. These means are in responses per minute and are based on the number of responses emitted in the last 12 minutes of the nine observation periods recorded under each condition. The degree of control over variation within conditions has been indicated by plotting a distance of ± 1 standard deviation about each mean.

Figure 1 shows that (a) the particular independent-variable manipulations used were effective in producing different rates of responding,³ and (b) the within-condition variance in the dependent variable is of such an order as to warrant the assumption that the same operations yielded relatively constant behavioral effects, both on repeated occasions and from animal to animal.

Since the assumption of constant effects under constant external conditions is tenable, an analysis may be made of the relations among the effects of the two manipulated conditions. Figure 1 has indicated that the magnitude of effect produced by a given deprivation change depended upon the schedule by which reinforcements were delivered. In order to examine the nature of this dependency, the data have been replotted as shown in Fig. 2, where the average rate at each deprivation time under the 1-minute VI schedule is plotted against the rates developed at corresponding deprivations under the 2-minute and 3-minute schedules. These trends are linear and, in both cases, straight lines fitted to the data will have intercepts near the origin. The fitted lines in Fig. 2 have been drawn under the assump-

³The appropriate error-variances not being significantly heterogeneous (Bartlett's test), the F's for the effects of deprivations, schedules, and interaction, deprivation $\times$ schedules, are all significant ($P < 0.001$). The significance of these effects (although not the level) is immediately apparent from inspection of Fig. 1, and merely indicates the relative efficiency of the particular operations used for producing changes in the datum.

Figure 1. Average rate of responding as a function of deprivation time for each schedule.

tion of zero intercepts, implying a simple proportionality between the rates of responding at corresponding deprivation levels and under different VI frequencies of reinforcement. The equations of the fitted lines are $r_1 = 1.35r_2$ and $r_1 = 2.43r_3$, where r_1 , r_2 , and r_3 are the 1-minute, 2-minute, and 3-minute rates, respectively. The analogous relation, $r_2 = 1.81r_3$, is not explicitly plotted in Fig. 2.

DISCUSSION

The proportional relation assumed between the average rates developed at corresponding deprivation levels under different VI schedules is apparently quite consistent with the present data. The particular assumption made in fitting the lines of Fig. 2 above can be tested readily under further experimental conditions, since it effects a maximum simplification in the form of the relation under consideration. The important functional property of the constants of proportionality is that their values are independent of the level of deprivation effect, and, apparently, are determined by some behavioral property of the schedules compared.

A relation analogous to that obtained here between the rates at corresponding deprivations under different schedules has been found by Dinsmoor (1) between the average rates under two discriminative stimuli at different deprivation levels. Dinsmoor found that after a discrimination was established the ratio of S^D to S^A rates remained invariant over a wide range of deprivation conditions. Although the operations differed considerably in the two experiments, the obtained relations are comparable in several respects. In Dinsmoor's experiment, the comparison is between the rates under two stimulus conditions, and is made at different constant deprivation levels. In the present experiment, the rates under different VI schedules are compared, again at different constant deprivations. In both cases the rates are related by a simple proportion, and, hence, their ratios are independent of the level of deprivation effect. In the present experiment, the value of the proportionality constant is attributable to schedule effects. In Dinsmoor's experiment, on the other hand, the value of the ratio between S^D and S^A rates is, presumably, attributable to the difference between the two stimulus conditions which function as S^D and S^A .

Figure 2. Rate of responding under the 1-minute VI as a function of the rate at corresponding deprivations under the 2-minute and 3-minute VI's.

In fact, the ratio of S^D to S^A rates becomes a convenient measure of the "discriminability" of the stimuli, since it is not affected by deprivation.

This analogy between the two experiments may become strained if we speak of the ratio of the rates under different VI schedules as an index of the organism's capacity to discriminate the difference in frequency of reinforcement under the two schedules. This is particularly so in the present case, where the operations do not involve a discrimination procedure (as might have been used, for example, with multiple schedules), and comparisons between schedules are also comparisons between groups of animals. Nevertheless, the interaction of deprivation and schedule effects (for VI schedules) and the interaction of deprivation and discriminative effects appear to be functionally similar. In both cases a quantity has been obtained which is invariant under changes in deprivation effect; and, in both cases, the *form* of the obtained relation is probably invariant over a considerable range of changes in both independent variables.

This similarity of results between Dinsmoor's experiment and the data presented above is particularly noteworthy in view of the rather large differences in the operations involved. These include differences in the amount of reinforcement used, and, very probably, also in the bar characteristics. Most importantly, however, the deprivation manipulations differ considerably in the two cases. In the present experiment, deprivation changes were produced by changing the times since the last feeding, with a fixed maintenance program. Dinsmoor, on the other hand, produced changes in deprivation by altering the amount of the daily ration so as to produce differences in the percentage of free-feeding weight at a constant interval after the last feeding. The similarity between the deprivation effects in the two cases, then, would not appear to depend upon the particular operations used to produce these effects.

Dinsmoor (1, p. 69) has suggested that a multiplicative relation between deprivation effects and those of other variables extends over an even wider range of experimental conditions. He cites the experiments of Perin (3) and Williams (11) as showing that the effect of deprivation differences upon the number of responses to an extinction criterion may be removed by a multiplicative constant. Dinsmoor also notes Skinner's finding, that when a constant deprivation difference is maintained between two groups of animals during FI reinforcement and subsequent extinction, then the ratio of the pre-extinction rates under the two deprivations is maintained throughout extinction (7, 8).

Although these phenomena are undoubtedly related in some way to the findings discussed above, the exact nature of the relation is not immediately apparent. The experiments of Perin and Williams were poorly controlled in terms of the absolute amount of variation in the dependent variable (although a better controlled experiment by Strassburger (10) has subsequently confirmed most of the findings). More importantly, however, the constant required to remove differences in deprivation effect in the Perin-Williams-Strassburger type of experiment is not independent of the deprivation difference; rather, it is a function of this. Similarly, in Skinner's experiment (7, 8), the ratio of the pre-extinction rates under the same schedule appears to be associated with the deprivation difference between the groups. What this experiment shows is that the same proportion is maintained throughout extinction.

Apparently, this implies still another sort of constancy, namely, between the average rate and the rate of change of the rate during extinction. In order to superimpose the extinction rates at different times by means of the ratio of the pre-extinction rates, the deceleration at any time must be proportional to the rate at that time. This merely indicates that: (a) in extinction after FI reinforcement, we are dealing with some kind of exponential decay in rate as a function of time; and (b) although the deprivation level affects the *initial* rate during extinction, the rate of decrease in the rate *relative to* its value remains independent of the deprivation effect.

In any case, neither of these findings with respect to deprivation effects during extinction can apparently be directly related to Dinsmoor's results, or to those presented above, until the matter has been more thoroughly explored experimentally. In extinction we are dealing with a special case of a change in state produced by an altered reinforcing contingency. Further experiments should be conducted to examine the interaction of deprivation with other effects during such changes in state. The confirmation of a multiplicative interaction in such cases would constitute an important extension of the kind of invariance obtained in the present experiment.

SUMMARY

1. The effects of deprivation and frequency of reinforcement on variable-interval responding were investigated, using food reinforcement, food deprivation, and bar pressing in the white rat.
2. Both independent variables significantly affected the rate of emission; the interaction of deprivations and schedules was significant. In general, equal increments in deprivation produced greater increments in rate of responding where the frequency of reinforcement was higher. The rates at corresponding deprivations and under different frequencies of reinforcement were approximately proportional over all deprivation conditions used.
3. The proportional relation between the average rates at corresponding deprivations under different schedules was discussed in relation to previous findings regarding the interaction of deprivation and discriminative effects, and regarding the effects of deprivation during extinction.

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