throughout the 2-hour sessions. As is shown in Fig. 2*A*, a typical record, the fish almost immediately drove the temperature down from 38°C to approximately 35°C. In almost every 2-hour session, the fish showed a burst of responses when the lever was initially made available. Within a few minutes the temperature was brought down to the level later maintained. The fish very rarely allowed the temperature to rise above 36.5°C and rarely pushed it down below 33.5°C. The temperature remained with this 3-degree range almost all of the time. The maintained temperature of about 35°C in this experiment is much higher than the value determined by Fry (*1*) for temperature selected by goldfish in a thermal gradient (27°C for fish adapted at 25°C or more). It is likely that the fish in this experiment were setting the tank at a maximum comfortable temperature. That is, 35°C may be about the highest temperature at which these fish do not get aversive thermal feedback from their environment.

In the second series of experiments, as soon as the lever was made available at the initial temperature of 24.5°C, the water bath was gradually heated to 41°C over a ½-hour period. Sessions lasted 2 hours from the introduction of the lever. In this situation, fish were able to maintain their tank at a given temperature with much less work than under the first procedure. They were not required to bring the temperature down initially to the selected level. If amount of work is an important variable in controlling thermoregulatory behavior, one might predict that the fish would maintain a lower temperature in the second experiment than in the first.

The results of this second experiment, as shown by the examples in Fig. 2, *B* and *C*, indicate that there is no difference between the temperatures maintained under the two sets of conditions. Typical records for fish SG 106 under both conditions are shown in the figure.

Fish usually did not press the lever much at temperatures below 33°C in the second experimental series. They usually began pressing consistently at approximately the maintained temperature of 35° to 36°C. Some records (Fig. 2*B*) show a gradual upward drift in temperature as the session continues. Others show relatively little drift and very close regulation (Fig. 2*C*).

Control experiments have indicated that the increased activity of the fish at higher temperatures and the slight increase in oxygen tension of the water associated with reinforcement are not important factors controlling thermoregulatory behavior in this situation.

The results of these experiments indicate that the goldfish will regulate its body temperature within certain limits under a constant high-temperature stress. It has been suggested (*5*) that temperature selection in fish can be accounted for as a direct effect of temperature on the locomotion of fish. This study indicates that other factors are involved in temperature selection, since the goldfish will perform an arbitrary response to change the temperature of its environment (*6*).

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References and Notes

1. F. E. J. Fry, *Publs. Ontario Fisheries Research Lab.* **55**, 5 (1947).
2. B. Weiss and V. G. Laties, *J. Comp. and Physiol. Psychol.* **53**, 603 (1960).
3. F. E. J. Fry, J. R. Brett, G. H. Clawson, *Rev. can. biol.* **1**, 50 (1942).
4. C. B. Ferster and B. F. Skinner, *Schedules of Reinforcement* (Appleton, Century, Crofts, New York, 1957).
5. K. C. Fisher and P. F. Elson, *Physiol. Zoöl.* **23**, 27 (1950).
6. This investigation was part of a thesis submitted in partial fulfillment of the requirements for the Ph.D. degree by one of us (P.N.R.). The research was supported in part by grants from the National Institute for Neurological Disease and Blindness (B-1941) and the Nutrition Foundation.

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Progressive Ratio as a Measure of Reward Strength

Abstract. Four rats were trained to press a lever on a ratio schedule of reinforcement in which the number of lever presses required on each consecutive run increased by a fixed increment. Both concentration and volume of the reward were varied. Relationships were obtained between reward and deprivation variables and the size of the final completed ratio run.

For many years, experimenters in the field of animal motivation have utilized the obstruction technique as a means of determining the relative strength or "attractiveness" of rewards under various motivational conditions. The technique consists of interposing an obstruction, such as an electrified grid, between the animal and some reward such as food. Initially, the rationale for this procedure was that the greatest intensity of electric current which the animal would cross should correlate with variations in reward and deprivation. Implicit in this line of reasoning is the view that over a broad range of values, the "breaking point" of an animal's behavior should be a good measure of the relative effectiveness of motivational variables. However, due to the great variability in behavior associated with repeated electric shocks, experimenters have been unable to establish a reliable "breaking point." Instead, workers have used the number of crossings of a grid with a constant charge during a fixed period of time as an index of reward strength (*1*). Nevertheless, the repeated use of electric shock results in highly variable data which are particularly difficult to interpret in the case of individual animals.

The experiments reported here were designed to overcome the shortcomings of obstruction methods by using as a measure of reward strength the largest number of responses which an animal will make to obtain a reward. With this technique, a stable "breaking point," which varies reliably with changes in reward and deprivation, can be obtained.

The subjects of these experiments were four albino rats from the colony at the Walter Reed Army Institute of Research. Their weights at the start of the experiment ranged from 250 to 450 g. The apparatus was a modified Skinner box adapted for liquid reward and controlled by a system of relay-operated switching circuits.

After a brief initial period of training to press the lever to receive 0.05 ml of sweetened condensed milk as a reward, the rats were placed on the progressive ratio schedule, which requires that the animal emit an increasing number of responses in order to obtain each reward. The ratios used in these experiments increased by an increment of two, so that the rats were required to emit two responses for the first reward, four for the second, six for the third, eight for the fourth, and so on. Each run of responses in this increasing schedule is called a ratio run. A timer in the circuit was set so that if at any time during the experiment the animal failed to respond for a period of 15 minutes, the session was automatically terminated (*2*).

In the first experiment, sweetened condensed milk was diluted with various amounts of water on different days of the experiment. The order of presentation was random, and the animals were maintained ad libitum on lab chow and water in the home cage. Figure 1 (top) shows the results of this experiment. The number of responses in the last complete ratio run before the animal failed to respond for a 15-minute period are plotted as a function of the concentration of the milk reward. Each point represents the median of six test sessions. The last point on each curve represents the data obtained when the reward was water alone. As the concentration of sweetened condensed milk declines, the magnitude of the final ratio run also declines. It is interesting to note that even when animals have been maintained ad libitum on lab chow and water, sweetened condensed milk in high concentrations still can function as a relatively potent reward. This is illustrated by the striking difference between the first and last points of each curve.

In the second experiment, the amount of food consumed daily by each rat was regulated so that over a period of 4 to 6 weeks its body weight was gradually reduced to 80 percent of normal. When the rats had reached 80 percent of their normal weight, their food ration was systematically increased so that over a similar time period they were returned to their normal weights. During both of these periods, the testing schedule described above was continued. The concentration of the milk reward was held constant at equal volumes of milk and water. Water was available ad libitum in the home cage. At the termination of the experiment, the data were grouped into 5-percent intervals of weight. The solid lines in Fig. 1 (bottom) show the results of this experiment. Each point represents the median of the data of 9 to 14 sessions. The curves indicate that as the animals' body weights diminish from normal, the number of responses in the final ratio run increases markedly.

The third experiment was carried out in the same manner as the second, except that the volume of the milk reward was increased from .05 to .20 ml. The effects of this increase are shown by the broken lines in Fig. 1 (bottom). The general trend of the .20-ml curves is the same as the .05-ml curves. A comparison of the .20-ml and .05-ml curves indicates a small but rather stable increase in the final ratio run under the .20-ml condition. This increase is most apparent at the higher levels of deprivation.

One may inquire as to what extent these results may reflect an interaction with progressive satiation. Whatever satiation effects may be present are most likely quite small; for, during initial lever-pressing training, it was noted that while deprived of food, each rat ingested 12.0 to 15.0 ml of milk. This is in sharp contrast to the 2.0 to 3.0 ml of milk consumed under comparable conditions on the progressive ratio schedule. Furthermore, if progressive satiation were a principal determiner of progressive ratio performance, one could expect increases in the concentration or volume of the milk reward to diminish the number of responses in the final ratio run. This was clearly not the case.

A comparison of the upper and lower halves of Fig. 1 illustrates the effects of two aspects of amount of reward. The upper half represents the effects of variation in the concentration of the reward while the lower half depicts the effects of differential volumes of reward as a parameter. Investigations are currently in progress in this laboratory in which the volume of the reward is being varied over a wide range in order to gather further data on the relationship between reward volume and reward "attractiveness." In addition, the size of the increment by which each ratio run increases is being systematically varied.

Since performance on the progressive ratio schedule seems to correlate well with variations in reward and deprivation parameters, it may well find application as a means of evaluating the relative rewarding properties of intracranial self-stimulation.

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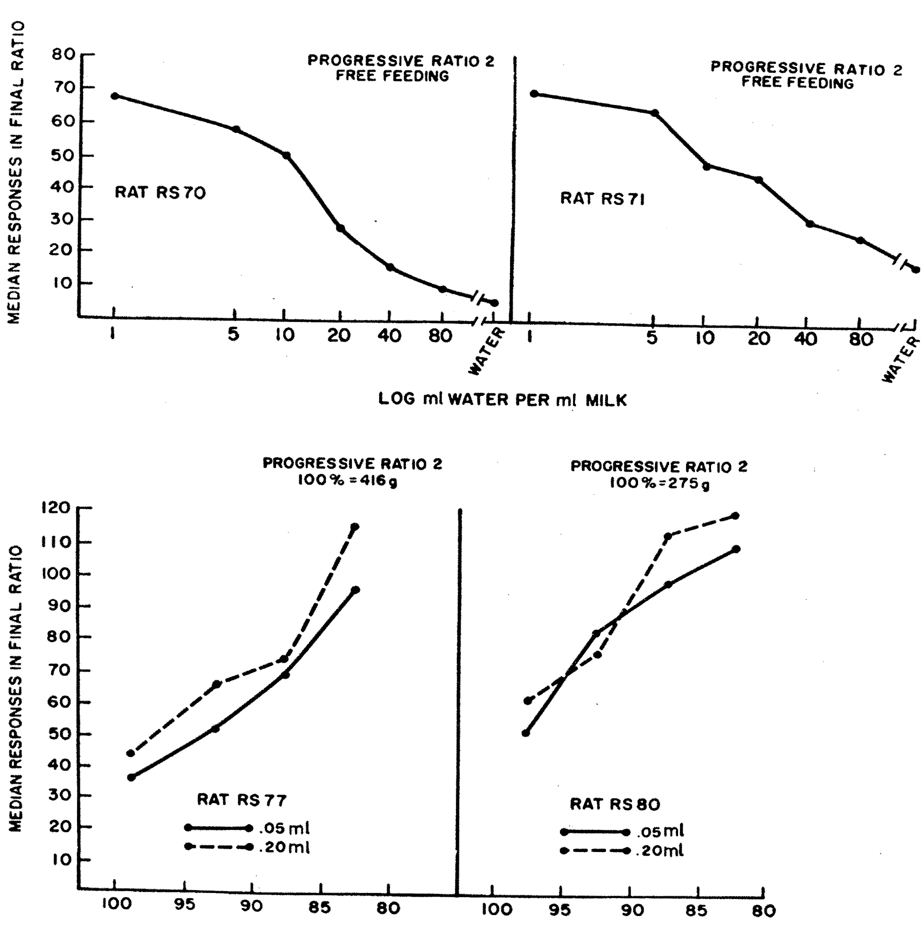

Fig. 1. The number of responses in the largest completed ratio run is plotted as a function of several levels of reward and deprivation variables. (Top) The effect of decreasing the concentration of the reward. (Bottom) Effect of increasing food deprivation and the volume of the reward.

References and Notes

1. F. A. Moss, *J. Exptl. Psychol.*, **7**, 168 (1924); J. C. Warden *et al.*, *Animal Motivation: Experimental Studies on the Albino Rat* (Columbia Univ. Press, New York, 1931).
2. Experiments utilizing progressive ratio requirements for switching between one reward schedule and another have been reported by J. Findley [*J. Exptl. Anal. Behavior* **2**, 123 (1958)].

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