these leaves and control leaves were treated for 4, 6, 8, 10, or 12 sec at 50°C at 205 hours after inoculation. The ED_{50} for the treated rust was 8 sec at 50°C, and for the control rust it was 5.5 sec at 50°C, as indicated by continuation of mycelial growth and spore production.

It is believed that acquired heat tolerance may be an important factor in the ecological heat tolerance of plants and their pathogens (*3*).

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29 May 1961

Thermal Reinforcement and Thermoregulatory Behavior in the Goldfish, Carassius auratus

Abstract. Goldfish in a warm environment can cause a small drop in the temperature of their environment by pressing a lever. The fish regulate the temperature of their environment, keeping the temperature between 33.5° and 36.5°C most of the time.

The rate of activity and metabolism of poikilotherms is largely determined by the temperature of their environment. Yet thermal adaptation in these animals tends to reduce the effects of temperature and poikilotherms can also change their body temperature by moving from one environment to another.

The process of temperature selection has been investigated in a number of poikilotherms, including the goldfish. Fry (*1*) has found that goldfish, when placed in water containing a temperature gradient, spend most of their time in water within a certain temperature range. This finding suggests that temperature might be used to reinforce learning in these fish. If a goldfish is placed at a temperature that is considerably different from its preferred temperature, will it perform some arbitrary response in order to bring the temperature of its environment closer to its preferred temperature? Furthermore, if temperature change can be used as a reinforcement, will the fish regulate its body temperature by regulating the temperature of its environment? Weiss and Laties (*2*) have shown that the albino rat, when placed in a cold environment, will press a lever for heat reinforcement. No similar experiment has been performed with a poikilotherm. In the experiment presented here, it is demonstrated that goldfish will work to produce certain temperature changes in their environment, and that, when given the opportunity to control their body temperature, they will do so to a certain extent.

The experimental apparatus is shown in Fig. 1. A small goldfish (3 to 8 g) was placed in a 1-pint container of water. This container rested in a constant-temperature water bath. During training the bath was initially at a temperature of 24.5° ± 0.5°C. The home container of the fish was kept at 23° ± 1°C. The fish was given 10 minutes to adapt to the experimental container, and then the temperature of the water bath was gradually raised to 41°C over a period of about ½ hour. The lethal temperature for these goldfish is approximately 41°C (*3*). When the temperature in the experimental container reached between 30° and 35°C, training was begun. Measured amounts of cold water were introduced into the container at irregular intervals. Each cold reinforcement consisted of a 1-sec flow of cold water (2 to 3 ml) from the distilling tube mounted above the container (see Fig. 1) and produced a transient drop in temperature of approximately 0.3°C. A small light bulb mounted above the container was lighted during the 1-sec reinforcement period. Each fish received approximately 50 reinforcements in each of two training sessions.

In the third session, the lever was placed in its appropriate position, and the lever target was located behind the hole in a Plexiglas lever guard (Fig. 1). In order to actuate the lever, the fish had to insert its head through the hole and push at the target. The lever guard prevented chance operation of the lever by the swimming movements of the fish. When the temperature rose to above 30°C, training for lever pressing was begun. The method of "successive approximations" was employed (*4*). In this method, the reinforcement is first given whenever the animal is near the lever, then when the animal touches the lever, and finally only when the animal presses the lever. Most fish learned to press the lever within 2 hours after the onset of training. Seven small goldfish were trained.

The fish were then placed in a "titra-

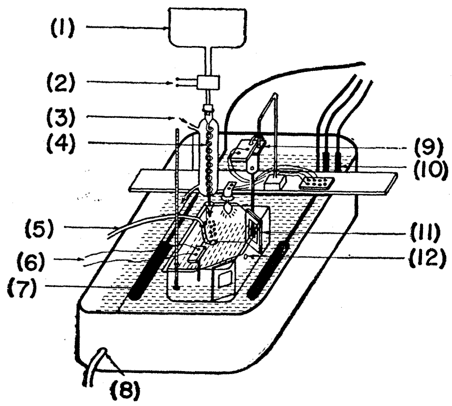

Fig. 1. Device for the study of regulatory behavior in the goldfish. 1, Water supply; 2, electric valve; 3, cold water; 4, distilling tube; 5, air line; 6, wires from thermistor; 7, heater; 8, "constant level" hole; 9, lever assembly; 10, thermostats; 11, lever guard; 12, "constant level" hole.

tion" situation. The temperature of the water bath gradually rose and leveled off at 41°C. By pressing the lever for squirts of cold water, the fish could lower the temperature in its container. The temperature was maintained at 41°C for the entire session, once it had reached this level. Thus, a constant temperature stress was provided for the fish.

Two procedures were employed in experimental sessions. In the first procedure, the temperature of the experimental container was raised to 38°C before the fish was permitted access to the lever; the fish was then given access to the lever for 2 hours. The lever-pressing responses and temperature in the container were recorded continuously

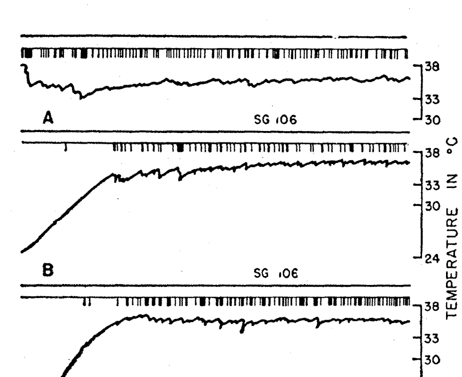

Fig. 2. Typical records of lever-pressing responses of goldfish and temperature in the container. *A*, Fish drives down environmental temperature. *B* and *C*, Fish prevent the temperature from rising above 35° to 36°C.

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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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