tions per second. The frequency of wing-beat-induced sound within each pulse was quite variable, generally falling between 150 and 300 cy/sec. A significant correspondence between pulsation rate and temperature was manifested, with the rate increasing by approximately 1.4 pulses for each rise of 1°C (Fig. 2).

The sound produced was of such low magnitude as to approach the limits of sensitivity of the microphone and amplification equipment. In no known instance have these sounds been detected by the unaided human ear. The amplitude of wing excursion, which probably does not exceed 1 mm, appears to differ markedly among individual males. In most trials, interpretable signals were seen on the oscilloscope screen only when the male was oriented near the bottom of the cage with its vibrating wing close to the head of the microphone. A few males produced relatively strong sounds regardless of their location in the cage, and a few produced no discernible sounds at any time during their wing vibration behavior (*4*).

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#### References and Notes

1. H. T. Spieth, *Bull. Am. Mus. Nat. Hist.* **99**, 399 (1952).
2. M. Bastock, *Evolution* **10**, 421 (1956); A. Manning, *Behaviour* **15**, 123 (1960).
3. E. Mayr, *Evolution* **4**, 149 (1950).
4. This report is Citrus Research Center and Agriculture Experiment Station paper No. 1373, Univ. of California, Riverside.

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## Oxygen-Motivated Behavior in the Goldfish, Carassius auratus

*Abstract.* Goldfish placed in deoxygenated water learned to interrupt a light beam in order to obtain brief exposure to aerated water. The training procedure brought this behavior under the control of arbitrary visual stimuli.

Swimming seems to be the obvious choice for studying the behavioral reactions of fish to variations in available oxygen. In two recent studies (*1*) investigators have exposed fish to spatial gradients of oxygen tension and have observed their locomotion. Although swimming may occur in nature as a reaction to a deficiency of oxygen, it is not necessarily an ideal dependent variable in behavioral studies. For example, it is not clear to what extent swimming is an acquired or a reflexive response to oxygen deficit. If it is to any degree acquired, the learning process may go on outside as well as during the course of the experiment. Moreover, without some restriction on the direction of the fish's movement with respect to the oxygen gradients in the experimental chamber, swimming may become associated with both increases and decreases in available oxygen, thus creating an ambiguity in the relation between behavior and its consequences. To these difficulties must be added the problems of recording and quantifying swimming itself.

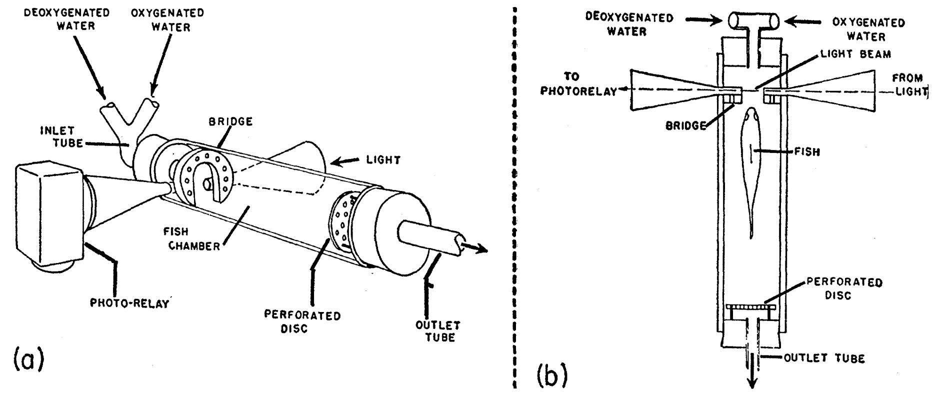

Fig. 1. Experimental chamber. (*a*) General view and (*b*) plan.

In the experiment described here a relatively arbitrary response of the fish was selected for study; the response is associated with temporal, rather than spatial, variations in oxygen tension, and the relation between the response and the changes in available oxygen is under the immediate and precise control of the experimenter.

The experimental chamber (Fig. 1) comprised a 4½-inch-long, clear plastic tube with a 1-inch internal diameter. Water flowed through this tube at a constant low rate (500 ml/min). The fish maintained its position in the tube by very slow and continuous swimming. A small perforated disk at the downstream end of the chamber prevented the fish's tail from lodging in the outflow tube.

Near the front end of the chamber was a small plastic constriction or bridge with an opening just large enough to admit the fish's head without contact. A light beam passed across the tube just upstream of this constriction. The interruption of this beam, which activated a photorelay, comprised the response. The goldfish learned to swim forward and back in a relatively stereotyped manner to break this light beam with its head. The bridge minimized chance interruptions of the beam resulting from general activity of the fish.

The water flowing through the chamber came from one of two sources. The first was equilibrated with air. The oxygen content of the second supply was reduced in a deoxygenating column through which nitrogen was forced. The modified Winkler test showed that this system produced almost complete deoxygenation. The water was recirculated, passing through a glass-wool and carbon filter. It was maintained at 25° ± 0.5°C by thermostatically controlled heaters.

Two electrically operated valves im-

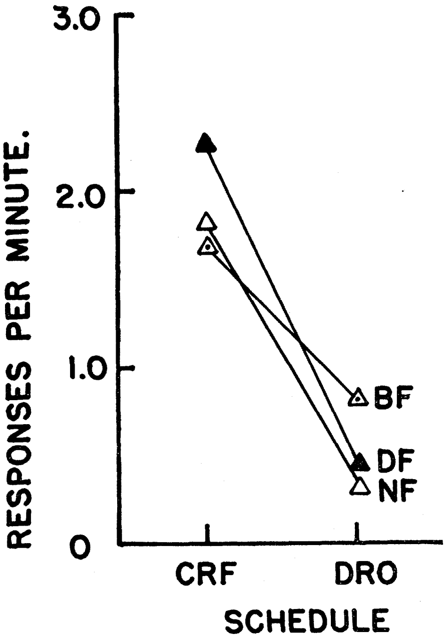

Fig. 2. Rates of responding of three fish, DF, BF, and NF. In each case the medians of daily mean rates of responding under the two experimental conditions are plotted. In the first condition (CRF) all responses were reinforced. In the second (DRO) reinforcement followed the absence of a response for 20 seconds.

mediately above the experimental chamber permitted the supply to the chamber to be switched rapidly from one source to the other with negligible change in flow. The operation of these valves, the presentation of visual stimuli through the walls of the chamber, and the recording of responses were executed automatically by relay equipment.

The goldfish, weighing 4 to 6 g, was placed in the chamber, which was immediately sealed, filled with water, and freed of all air bubbles. It was trained for two procedures which alternated every 15 minutes throughout each daily 2-hour session. In the first procedure, each response of breaking the light beam was followed by a 15-second period in oxygenated water, at the end of which the water in the chamber reverted to the deoxygenated supply until the next response. A red light was illuminated to the right of the chamber while this procedure was in effect. In the second procedure the water in the chamber was deoxygenated until 20 seconds had elapsed without the occurrence of a response. Each response postponed the onset of oxygenated water for 20 seconds. At the end of 20 seconds without a response, oxygenated water was introduced for 15 seconds. A green light to the left of the chamber signalled that this procedure was in effect.

The three fish used showed steady responding within the first 10 minutes of the training. The rate of responding rose to a maximum over the first 5 to 7 days and then fell gradually to a steady intermediate level over a period of 20 days. Regular responding was maintained for as long as the fish were subjected to these procedures, in some cases for several months of daily experimentation.

The fish initially responded at an inappropriately high rate at the beginning of the 15-minute periods during which responding postponed reinforcement. Then, toward the end of these periods, the rate declined and reinforcements began to occur. After several sessions, these inappropriate responses disappeared, and the performance came under the control of the two stimulus lights. The fish then swam quietly with little movement toward the light beam. The mean response rates on the two procedures showed no overlap within an experimental session after the first few days of training. Figure 2 shows the medians of the daily mean rates for three fish after their rates of responding had stabilized.

The fish showed a systematic tendency to respond at a higher rate in the first 15 minutes of the daily session. This may be associated with the brief exposure to air during transfer from the aquarium to the chamber, and with the increase in metabolic rate associated with handling. The decline in rate of responding during the first 20 to 30 sessions may arise from long-term habituation to restraint or from acclimation to lower oxygen tensions (*2*).

This experiment demonstrates that the goldfish is capable of regulating its respiratory environment by means of acquired behavior, and that this behavior can be brought under rather precise stimulus control. It provides a technique well adapted to studies not only of the behavioral effects of respiratory agents but also of many other physiological variables associated with the immediate environment of the fish (*3*).

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### References and Notes

1. J. R. E. Jones, *J. Exptl. Biol.* **29**, 403 (1947); C. M. Whitmore, C. E. Warren, P. Doudoroff, *Trans. Am. Fisheries Soc.* **89**, 17 (1960).
2. C. L. Prosser, L. M. Barr, R. D. Pinc, C. V. Lauer, *Physiol. Zool.* **30**, 137 (1957).
3. This investigation was part of a thesis submitted in partial fulfillment of the requirements for the Ph.D. degree. The research was supported by National Science Foundation grants G-6435 and G-14341 and by a gift from CIBA Pharmaceutical Products, Inc., to Harvard University.

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## Biological and Oceanographic Observations under an Antarctic Ice Shelf

*Abstract.* Animal life has been shown to exist under the Ross Ice Shelf, from samples obtained with bottom-sampling equipment through naturally occurring cracks in the permanent shelf ice. An abundant fauna, comprising at least nine phyla, was found on a mud and rock bottom. This fauna differs somewhat from that found under nearby seas periodically covered with sea ice 2 to 3 meters thick.

During November and December 1961 the White Island and Koettlitz Glacier regions of the Ross Ice Shelf, Antarctica (*1*) (Fig. 1), were examined, and sampling of the bottom marine fauna beneath a floating ice shelf was accomplished for the first time. These regions were chosen as investigation sites because of the presence of Weddell seals, *Leptonychotes weddelli* (Lesson). The presence of seals on the shelf ice suggests that direct passages communicate with the ocean beneath.

Table 1. Major zoological groups collected at White Island and Koettlitz Glacier.

| Group | White Island | Koettlitz Glacier |
|---|---|---|
| Foraminifera | + | |
| Monaxonid porifera | + | + |
| Thecate hydroida | + | + |
| Athecate hydroida | + | |
| Alcyonacean alcyonaria | + | |
| Actiniaria | + | + |
| Nematoda | + | + |
| Branching ectoprocta | + | |
| Encrusting ectoprocta | + | + |
| Nereid polychaeta | + | |
| Sabellid polychaeta | | + |
| Other polychaeta | + | + |
| Pycnogonida | + | + |
| Copepoda | + | |
| Isopoda | | + |
| Tanaidacea | + | |
| *Orchomenella proxima* | + | + |
| Other amphipoda | + | |
| Patellacean gastropoda | | + |
| Echinoidea spines | | + |

White Island, a basaltic island located at latitude 78°10′ S, longitude 167°20′ E, is about 22 km from the open sea during the late antarctic summer. The shelf ice in this region varies in thickness from approximately 5 m at the seaward edge of McMurdo Sound to 70 m a few miles east of White Island. A narrow system of crevasses and disturbed shelf ice occurs along the northwestern coast of White Island and extends several miles northeast of the island. A more extensive crack system was found in the Koettlitz Glacier region, 78°13′ S, 164°10′ E, 28 km from the leading edge of the Ross Ice Shelf.

Three collecting sites were established. Collections from White Island were taken at depths of 43 and 75 m. All material from the Koettlitz area was taken at a depth of 40 m. A large number of thin ice platelets were present in the narrow White Island cracks, in some areas extending to a depth of 30 m. These ice platelets made it quite difficult to lower the collecting apparatus; however, successful use was made at all collecting sites of an orange peel grab 30 cm in diameter, cylindrical metal traps 15 by 60 cm, and Nansen bottles equipped with reversing thermometers. The absence of ice platelets at the Koettlitz Glacier site made it possible to pump several hundred liters of water and filter it through a plankton net with a mesh of 54 threads per inch. Oxygen and salinity determinations were made by standard oceanographic techniques (*2*).