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## Physiological Response to Air Exposure in Codfish

When diving mammals and birds submerge they exhibit a series of characteristic phenomena. The heart rate slows down. Lactic acid accumulates in the muscles, but only a very little leaks out into the circulation, because blood flow through the muscles is strongly depressed. This part of the picture is virtually the same whether the animal is quiet or active during the dive. In the recovery after the dive, circulation increases, and the lactic acid from the muscles pours into the blood. These and other adjustments are strikingly developed in many diving mammals and birds and have been found, in a more or less pronounced degree, in every warm-blooded animal where such investigations have been made. Man also frequently develops a pronounced bradycardia during diving, even while swimming vigorously (*1*).

Unpublished experiments performed at Woods Hole, Mass., several years ago indicated that similar mechanisms operate in dogfish (*Squalus*) when they are taken out of water, and these observations led to the present investigation (*2*) on codfish (*Gadus callarias*) at the Biological Station at Drøbak, Norway.

Heart rate and lactic acid in blood and muscles were determined (i) when the fish were resting quietly in the water, (ii) when they were taken out of water and left struggling in air for 4 minutes, and (iii) when they were placed back in water for recovery. Heart rates were taken on the same fish throughout the sequence, but lactic acid samples were, in all cases, taken from different fishes and give therefore a statistical picture of the sequence. Heart rates were obtained by means of an electrocardiograph. Blood or muscle samples for lactic acid determinations were taken immediately after removing the fish from the water and were analyzed colorimetrically (*3*).

When the fish was taken out of water the heart rate dropped within a few seconds to half or less of normal (Fig. 1), and this bradycardia persisted even through violent muscular activity. When the fish was put back in water the normal pulse rate was rapidly restored.

In the muscles the lactic acid rose to a maximum during the air exposure and fell as soon as the fish was put back into the water. In contrast, the blood lactic acid remained low during the air exposure but rose in the recovery period and reached a maximum after some 5 to 15 minutes. As recovery proceeded, the lactic acid in blood and muscles slowly dropped back to normal (Fig. 1).

These events, produced by taking the fish out of water, are strikingly similar to those found when mammals and birds are submerged, and they very probably indicate the same sort of protective mechanisms against asphyxia—namely, a circulatory bypass of the muscles, which are thereby left isolated to operate on their own anaerobic resources. The bradycardia is very probably a direct consequence of the restricted peripheral blood flow, for at least in some diving mammals, the main arterial blood pressure does not drop during the bradycardia, which suggests that normal blood flow may be maintained in organs less capable of anaerobic functions than the muscles. The similarity of this mechanism to those present in diving mammals goes even further, inasmuch as bradycardia in the fish can be induced, just as in a seal, simply by frightening the animal. This "diving reflex" might seem to be an excellent idea for a flying fish, but how it could ever benefit a codfish is an evolutionary puzzle.

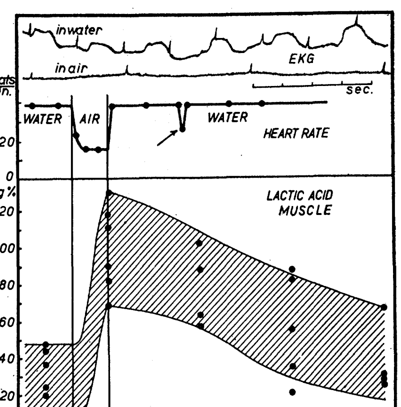


Fig. 1. Electrocardiograph tracings, heart rate, and content of lactic acid in muscles and blood of the codfish. The fish was taken out of water for 4 minutes. At arrow, hand was placed around submerged animal.

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## Irregular Maintenance Schedules and Drive

In animal experimentation the hunger drive is usually defined in terms of hours of food deprivation. Attention is rarely paid to the animal's prior history of deprivation. The deprivation history of an appetitive drive is controlled by means of a maintenance schedule—that is, the schedule of eating and deprivation intervals to which the animal is subjected over a period of time. If maintenance schedules affect subsequent behavior, then any variation from laboratory to laboratory may account for discrepant experimental findings.

Although it is known that irregular reinforcement profoundly affects animal behavior and is also a prominent feature of learning conditions outside the laboratory, almost nothing is known about the effects of irregular maintenance schedules. The present set of experiments represents a first attempt to study the effects of irregular food maintenance schedules on learning in the albino rat (*1*). It is expected that irregular schedules would elevate the drive effect of the deprivation interval used at time of testing.

In experiment 1, two groups of 70-day-old rats were placed on the following food maintenance schedules: a regular (*R*) group ($N = 5$) received 12 g of mash every 12 hours, and an irregular (*I*) group ($N = 6$) averaged the same amount of daily food intake but experi-