THERMAL RECEPTION IN FISHES

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I

The results of several investigators along with the fact that spinal cutaneous nerves of catfish showed no impulses for temperature changes between 0 and 35°C. led Hoagland to suggest that certain special receptors of the lateral-line system may possibly serve as thermal receptors.

Wells (1914) has found that fish respond quickly to temperature differences in the water and evidently possess thermal receptors. Ward (1927, 1929, 1932) has shown that temperatures of streams play an important rôle in directing the migrations of salmon. It has been shown by Parker (1902, 1904), Hofer (1908), Parker and Van Heusen (1917), Hoagland (1932, 1933 *a*, *b*, *c*), and Dykgraaf (1933) that the lateral-line organs in fishes serve primarily as mechanoreceptors. Records of electrical responses from the lateral-line nerves of fishes obtained by Hoagland, and described in the papers just cited, also show that certain receptors of the lateral-line system are normally in a state of continuous activity, discharging impulses repetitively over their attached nerve fibers. These receptors were shown to be supplied by different nerve fibers of the lateral-line trunk from those supplying the purely tactile receptors. Relationships were established between the frequency of the "spontaneous" discharge of nerve impulses and the temperature of the receptors (0 to 35°C.). The frequency was found to increase with temperature according to the Arrhenius equation. Thresholds of thermal activation were demonstrated for the discharge of these special organs of the lateral-line system in the catfish, *Ameiurus nebulosus* Les.

With the view to investigating the rôle of the spontaneously active units as thermal receptors, the following behavior experiments were performed on *Ameiurus nebulosus* Les. (the common catfish), *Eupomotis gibbosus* L. (the common red-gilled sunfish), *Lepomis pallidus* Mitchill (the blue-gilled sunfish), and *Perca flavescens* Mitchill (the common perch). Three groups of each species were used: (1) *Normal.*—intact fishes; (2) *Cut.*—fishes with lateral-line nerves (ramus

lateralis X) cut just posterior to the gills on each side of the trunk; (3) *Control.*—animals whose skin was cut in the same place as those in Group 2, but with the lateral-line nerves left intact.

Modification of behavior in response to thermal stimulation was tested as a function of the lateral-line system in the trunk only; the effect of the head organs on the behavior of the fish was not tested. The head organs were left intact in all of the groups, and their effect, if any, upon response to changes in temperature was the same in all the experiments.

Animals were placed, one at a time, in an aluminum pan containing water in which was immersed a calibrated thermometer. The water was heated by means of an ordinary circular gas burner, and the fish's reactions to the rising temperature were noted. Extraneous conditions were kept constant throughout all the experiments. The water was changed before each trial. The behavior of the fish was independent of the rate of change (approximately 3 to 5°C. per minute) of temperature of the bath for the experimental ranges. Varying temperature ranges were used between the limits of 0° and 34°C.

II

The normal and control fishes became markedly active at specific "response temperatures" indicated in Table I, while the cut fishes became active only at considerably higher, lethal temperatures (37.0 ±1.5°C.), showing no activity at the response temperature of the normal fish. The responses were in the form of vigorous swimming movements and pushing against the walls of the container. At temperatures below the response temperatures the animals were, as a rule, quiescent in the water.

On repeating the experiments on a second group of catfish a year later, it was found that they did not respond consistently to the response temperature previously observed. The catfish were very restless and would not remain quiet long enough for the experiment to be carried out. Freshly caught, young catfish behaved similarly. No satisfactory reason could be found for this difference in behavior. A second group of red-gilled sunfish, however, behaved typically, and the mummichog (*Fundulus heteroclitus*), showed a characteristic response temperature. Instead of being placed directly in the pan,

TABLE I

	Catfish			Sunfish (red-gill)			Sunfish (blue-gill)			Perch			Fundulus		
	Response temperature (°C.)	No. of trials	No. of fish	Response temperature (°C.)	No. of trials	No. of fish	Response temperature (°C.)	No. of trials	No. of fish	Response temperature (°C.)	No. of trials	No. of fish	Response temperature (°C.)	No. of trials	No. of fish
Normal.....	27.6 ± 0.29	32	4	27.0 ± 0.18	36	4	27.7 ± 0.20	40	4	27.5 ± 0.13	28	3	26.7 ± 0.10	24	3
Cut.....	None	30	3	None	37	5	None	30	3	None	30	3	None	24	3
Control.....	27.3 ± 0.20	33	4	26.8 ± 0.18	24	3	27.4 ± 0.05	24	3	27.5 ± 0.02	30	3	26.8 ± 0.05	21	3

Table I shows the mean specific temperatures of response observed, with probable errors based on the number of trials as indicated. The cut fish became violently active at 37.0±1.5°C. and died quite soon after being heated to this temperature. The response temperatures of the cut fish are indicated by "none," since in the experiments they were heated only to about 34.0°C. in order that more than one trial could be made on each fish.

Fundulus was confined in a small beaker which was put in the pan. This did away with the random swimming movements which took place when the small *Fundulus* (about 1.5 inches) was placed in the pan. The second group of catfish were, however, not quieted by this procedure. The results of the experiments on *Fundulus* are also contained in Table I.

The behavior of the normal and control sunfish is especially interesting since they usually keel over laterally in response to a slight increase of temperature even before the thermometer records the change. The cut sunfish did not keel over in this way, although it was still capable of doing so. This indicates that the response is due to the activation of thermal receptors, since the fish could not have been warmed internally to any appreciable extent before a change in temperature was recorded by the thermometer.

From this last fact and from the data in Table I it appears that certain receptors of the lateral-line system are involved in thermal reception, probably in addition to those receptors concerned with mechanoreception, since fishes with the rami lateralis X cut do not react to temperature changes as do the intact (normal) or the control fishes.

SUMMARY

The reactions of catfish, sunfish, perch, and mummichog to temperature changes, as described in this paper, indicate that certain receptors supplied by the lateral-line nerve are concerned with thermal reception.

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CITATIONS

Dykgraaf, S., 1933, Untersuchungen über die Funktion der Seitenorgane an Fischen, *Z. vergleich. Physiol.*, **20,** 162.

Hoagland, H., 1932, Impulses from sensory nerves of catfish, *Proc. Nat. Acad. Sc.*, **18,** 701.

Hoagland, H., 1933 *a*, Electrical responses from the lateral-line nerves of catfish. I, *J. Gen. Physiol.*, **16,** 695.

Hoagland, H., 1933 *b*, Quantitative analysis of responses from lateral-line nerves of fishes. II, *J. Gen. Physiol.*, **16,** 715.

Hoagland, H., 1933 *c*, Electrical responses from lateral-line nerves of fishes. III, *J. Gen. Physiol.*, **17**, 77.

Hofer, B., 1908, Studien über die Hautsinnesorgane der Fische. I. Die Funktion der Seitenorgane bei den Fischen, *Ber. k. bayer. biol. Versuchsstation München*, **1**, 115.

Parker, G. H., 1902, Hearing and allied senses in fishes, *Bull. U. S. Fish Com.*, **22**, 45.

Parker, G. H., 1904, The function of the lateral-line organs in fishes, *Bull. Bureau Fisheries*, **24**, 183.

Parker, G. H., and Van Heusen, A. P., 1917, The reception of mechanical stimuli by the skin, lateral-line organs, and ears in fishes, especially in *Ameiurus*, *Am. J. Physiol.*, **44**, 463.

Ward, H. B., 1927, The influence of a power dam in modifying conditions affecting the migration of the salmon, *Proc. Nat. Acad. Sc.*, **13**, 827.

Ward, H. B., 1929, Further studies on the influence of a power dam in modifying conditions affecting the migration of the salmon, *Proc. Nat. Acad. Sc.*, **15**, 56.

Ward, H. B., 1932, Origin of the landlocked habit in salmon, *Proc. Nat. Acad. Sc.*, **18**, 569.

Wells, M. M., 1914, Resistance and reactions of fishes to temperature, *Tr. Illinois Acad. Sc.*, **7**, 1.