ELECTRICAL RESPONSES FROM THE LATERAL-LINE NERVES OF CATFISH. I

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INTRODUCTORY

The function of the lateral-line organs of water-inhabiting vertebrates has been a subject of interest to biologists for many years.Externally the lateral-line system is marked in fishes by rows of pores. The main lateral-line canal extends typically along the flank from head to tail and is a conspicuous marking on most fishes. In the head this canal branches into three stems, one of which passes forward above the eye, another forward and below the eye, and a third downward and over the lower jaw. Lying between the pores in the canal are sense organs composed typically of supporting cells and sensory cells. In the catfish Ameiurus nebulosus Les., the animal used in the following experiments, the receptive cells (neuromasts) lie close to the lumen of the canal, and at their distal ends very fine hair-like processes extend into the lumen (Brockelbank, 1925). The receptive cells are supplied by the lateral-line nerve which runs along below the canal. The neuroanatomy of the lateral-line system in Ameiurus has been described by Herrick (1901). The organs of the lateral-line canal are supplied by the vagus nerve which has terminations in the tuber- culum acusticum. The structures in the catfish are fairly typical of those in other fishes.

Fuchs in 1895 investigated the functions of the organs by recording action currents from the lateral-line nerves of the torpedo fish. He obtained negative deflections of his galvanometer from what he attributed to be action currents of the lateral-line nerve in response to tactual stimulation of the end organs. He failed to get responses to chemical stimulation or to changes in temperature. From these experiments he concluded that the lateral-line organs are tactile receptors.

Parker (1902, 1904) reviewed the literature concerning the function of the lateral-line organs and presented experiments describing the behavior of normal fishes and
those deprived of functional lateral-line organs in the presence of various types of stimulation. The experiments were carried out systematically on _Fundulus_ and confirmed with some seven other species of fish. Parker concluded that these organs are mechanoreceptors responding to low vibration frequencies in the water (six per second), and that they are not stimulated by light, heat, salinity of water, food, oxygen, carbon dioxide, foulness of water, water pressure, water currents, or sound.

In 1917 Parker and Van Heusen published a report on the mechanical stimulation of the catfish _Ameiurus nebulosus_. Responses of groups of catfish were examined after operations which rendered certain specific sense organs non-functional. There were eight groups of fishes ranging from those in which the three sets of possible mechanoreceptors—skin, ears, and lateral-line organs—were functional, through those in which any two or only one of these sets of organs were functional. One group was also examined in which all of the three types of receptors had been eliminated.

The skin of _Ameiurus_ was found to be stimulated by the dropping of water, by water currents, by a slow vibratory movement of the whole body of water, by the impact of a leaden ball on the end of the aquarium, and by low tones of a submerged telephone up to 172 double vibrations per second. The ear of _Ameiurus_ was found to be stimulated by slow vibratory movements of the whole body of water, by the impact of a leaden ball on the end of the aquarium, by a whistle blown in the air, and by telephone vibrations ranging roughly between 43 and 2700 double vibrations per second. Dropping of water and water currents did not stimulate the ears. The responses initiated from stimulating both ears and skin were locomotory. Fishes in which the auditory nerves had been cut and the skin anesthetized, but which maintained functional lateral-line organs, were found not to respond positively to any of the above stimuli. However, the receptivity of the lateral-line organs to certain types of stimuli was clearly seen in those groups of fishes in which the lateral-line organs were functional along with either the ears or the skin. In these groups the lateral-line organs seemed to inhibit responses normally initiated by stimulating the ears or the skin. Thus, in response to blows from a leaden ball on the end of the aquarium, when only the skin was intact, the percentage of responses was 27, but when both skin and lateral-line organs were effective the response fell to 11 per cent. When only the ear was intact the percentage of responses was 73, but when the ear was combined with the lateral-line organs the percentage dropped to 33. Probable errors were not computed, but owing to the numbers of observations these differences are evidently significant. The presence of lateral-line organs in both cases markedly reduced the percentage of responses. From their experiments Parker and Van Heusen concluded that the lateral-line organs of _Ameiurus_ respond to impacts of a leaden ball on the walls of the aquarium, to slow vibratory movements of the whole body of water, to the lower tones of a submerged telephone, up to approximately 344 vibrations, but not to a whistle blown in the air, to the dropping of water, to currents of water, or to the higher tones of a telephone. The responses to the
stimuli were found to be inhibitions of those responses initiated through the skin and the ears.

In view of the inhibitory action of the lateral-line organs, it occurred to the writer that an examination of the electrical responses of the lateral-line nerve of the catfish not only might shed light on the normal functioning of the lateral-line receptors, but might also furnish a clue as to the possible nature of the inhibitory processes involved.

EXPERIMENTAL

In the present experiments only the lateral-line organs in the side of the fish were studied; the organs of this system located in the head were not examined. Fishes were prepared for the experiments by cutting through the medulla with a knife. In some experiments the entire head was removed, in others cordotomy was performed so as to leave the circulation relatively intact. The nerve supplying the lateral-line organs was bared for about 1 cm. by removing the skin and covering tissues over the lateral-line streak just anterior to the dorsal fin. After careful freeing, the nerve was tied with a thread and cut at its proximal end. In this way a length of nerve was obtained which remained connected with the lateral-line organs of the posterior part of the fish's body. The fish was then immersed in water so as to cover the organs to be tested. In some experiments it was laid with its operated side uppermost in a glass dish with water coming up just to the incision; in others it was suspended tail down in a jar of water. The nerve, moistened with Ringer's solution, was drawn by the thread across silver, silver-chloride electrodes connected to the recording system.

The recording system consists of an eight-valve, resistance-capacity coupled amplifier which operates an iron armature oscillograph (Matthews, 1928). Some of the amplified action potential from the nerve was further increased by a subsidiary amplifier and recorded as sound on a loud speaker. Light from an arc lamp, partially intercepted by a stationary straight edge, is reflected from the oscillograph mirror into a camera, where motion of the oscillograph tongue upon which the mirror is mounted is recorded on moving bromide paper. Another portion of the light reflected from the oscillograph mirror is projected by rotating mirrors as a standing wave on a screen. In this way the experimenter can hear the amplified impulses from the nerve, see them on a screen, and photograph them when he so desires.

With the first lateral-line nerve investigated a curious phenomenon was apparent. Instead of the usual smooth base line with nerve impulses showing up as a result of specific end organ stimulation, great activity was spontaneously manifested from the apparently resting lateral-line system. The system was found to be continuously emitting nerve impulses at a high frequency, each nerve fiber apparently dis-
Fig. 1. Responses of catfish nerves; time marked in tenths of a second. The length of the spikes is proportional to the action potentials of the nerve fibers.

(a) Spontaneous firing of a lateral-line nerve.
(b) Baseline for nerve used in making Fig. 1a after crushing the nerve between the electrodes and its entrance to the body.
(c) Responses from a spinal nerve when the skin supplied by it is stroked by a feather. The bursts of impulses mark the stroke.
(d) Responses from a branch of a facial nerve supplying sense organs in the lower lip when the lip is stroked with a feather.
charging at a rhythm of its own independently of the other fibers. At first it seemed possible that this activity might be due either to an artifact of the apparatus or to injury of the nerve in the course of the operation. Control experiments show that these explanations are not tenable. The lateral-line system in *Ameiurus* normally appears to be in a state of spontaneous activity, and its specific responses to stimuli take place against this background of activity. Out of thirty-two nerves examined all but three were found to be spontaneously discharging. These three nerves, however, failed to show any response to stimulation of the lateral-line organs. The same stimulation produced characteristic responses from the twenty-nine spontaneously active nerves. It seems probable, therefore, that these three nerves were completely non-functional, due perhaps to injury from the operation.

Fig. 1a shows a typical lateral-line nerve firing spontaneously. This sort of activity goes on unabated throughout an experiment. In some cases there was no reduction in the spontaneous discharge several hours after the first record was made. The impulses are typically diphasic, although they can be made monophasic by crushing the nerve under the distal electrode.

That we have to do with nerve impulses and not with artifacts of the apparatus is further borne out by the fact that reducing the temperature of the preparation produces a marked decline in the frequency of the spontaneous discharge and of the rate of the conduction of the impulses (cf. Fig. 4). Cutting the nerve where it enters the body but leaving it on the electrodes and in physical contact with the body produces an immediate cessation of the spontaneous activity. The nerve is also silenced by anesthetics placed either on the nerve or on the end organs. Water on the exposed nerve also causes failure of the spontaneous discharge. Fig. 1b shows a typical smooth base line after cutting the nerve between its region of entrance to the body and the electrodes. This nerve is the same one used a few minutes previously for obtaining Fig. 1a. Sometimes failure of activity of the nerve occurred during an experiment. Drawing the nerve further along the electrodes frequently was sufficient to renew the discharge. Cutting the lateral-line nerve and canal midway between the original incision and the caudal end of the line of pores furthermore resulted in a substantial reduction of the density of the discharge due to the severance of connection of the neuromasts posterior to this second incision.
That the spontaneous activity is not a product of the operation is indicated by the last fact. Furthermore, rough treatment of the nerve, such as pulling, permanently stops all responses. The nerve lies just under the skin at the place of incision and may be cleanly dissected free without difficulty. Since it is cut at the anterior end of its freed length, it is not in connection with the central nervous system. Anatomically there is no reason to believe that the nerve distal to the electrodes makes connection with the spinal cord. The independence of the spontaneous activity from possible connections with discharging internuncial neurones of the cord was checked by pithing the cord. This operation has no effect on the activity.

Other nerves were examined in *Ameiurus*, but none were found to yield impulses spontaneously. The body cavities of several fishes were opened and spinal nerves were tested. Fig. 1c shows a typical response of a spinal nerve to touching with a feather the highly localized area of skin which it supplies. The base line is smooth. The nerve is only active in response to direct stimulation of the end organs. Fig. 1d shows typical responses obtained from a branch of the facial nerve supplying the lip and base of the maxillary barbel when the skin is lightly touched (cf. Hoagland, 1932–33). The smooth base line is apparent.

Changes in the frequency of the spontaneous discharge of the lateral-line nerve were found to be brought about by two kinds of stimuli: (1) mechanical stimuli; (2) temperature changes. No responses were elicited by chemical stimulation.

Lightly stroking the skin over the lateral-line organs was found to produce a marked increase in the frequency of impulses during the stroking. Fig. 2a shows a spontaneously firing lateral-line nerve and the increased density of discharge when the flank over the lateral-line is stroked with the tip of a feather. These responses were especially audible on the loud speaker. This finding is consistent with that of Fuchs (1895) who, however, records no evidence of spontaneous discharge from the nerve. His results are to be expected in view of the comparatively crude galvanometers then available which would not be able to separate the impulses due to single fibers. If the lateral-line system operates in the torpedo fish as it does in the catfish, continuous activity of the nerve would merely serve to set what would appear to be a stable base line for a relatively insensitive recording system. Only
FIG. 2. Responses of a lateral-line nerve to various mechanical stimuli.
(a) Responses of a lateral-line nerve to stroking the skin above the canal with the tip of a feather. An increased density of discharge marks each stroke.
(b) Effect of squirting a stream of water from a pipette against the lateral-line.
(c) Increase in density of discharge accompanying spinal swimming movements. Effects of two such movements are recorded.
(d) Effects of rippling the surface of the water which covers the lateral-line canal. Time in tenths of a second.
relatively gross changes of potential would cause a deflection from this base line.

Streams of water directed against the lateral-line from a pipette also produced an increase in the responses similar to those due to direct stroking (Fig. 2b).

The presence or absence of water over the lateral-line organs seemed to make no difference in the frequency of the spontaneous discharge. This was tested by recording the responses both before and after immersion of the flank of the fish in water and in some cases after subsequent siphoning off of the water. Prolonged drying of the skin ultimately produced a permanent cessation of all activity from the nerve.

Flexion of the body of the fish by means of a thread around its tail usually produced an increase in the density of discharge during the time of bending. In some preparations slow, spontaneous spinal swimming reflexes persisted when the body was immersed in water. These rhythmic movements often produced small additional bursts of impulses clearly audible on the loud speaker from the spontaneously firing neuromasts. Fig. 2c shows responses resulting from reflex swimming movements. The upper part of the trunk was stationary and the nerve did not move on the electrodes. It is probable that pressure from the surrounding tissues is the stimulus increasing the discharge of the neuromasts when the body is bent.

Fig. 2d shows responses to rippling the water with a feather.

The response to vibratory stimuli was peculiar. Three tuning-forks were used, giving respectively 100, 200, 250 double vibrations per second. These are within the range of frequencies which Parker found would stimulate the lateral-line organs of *Ameiurus*. Fig. 3a shows the response of a lateral-line organ to an electrically earthed tuning-fork of 200 vibrations after setting it in motion and pressing its shank against the outside wall of the glass vessel containing the preparation. The fibers of the lateral-line nerve which had previously been firing independently of each other now become synchronized and beat in a rhythm of their own, in this case about 40 beats per second. This rhythm seems to be characteristic of the tissue and is independent of the frequency of the tuning-fork, since frequencies of 100 or of 250 brought about the same frequency of beating as the fork with the
Fig. 3. (a) Synchronized rhythmic discharge of a spontaneously active lateral-line nerve at 40 per second when a vibrating tuning-fork giving 200 double vibrations per second is twice pressed against the outside of the vessel containing the preparation.

(b) Responses to pressure on skin receptors of a frog from a dorsal cutaneous nerve. The frog was placed in the same experimental setting as the catfish from which record (a) was obtained. The vibrating tuning-fork was pressed against the outside of the containing vessel as above, but no synchronous responses occurred.
frequency of 200. Only approximately 60 per cent of the preparations showed this response to tuning-forks. The remaining 40 per cent were unresponsive to the forks, but were responsive to other forms of mechanical stimulation.

To be sure that the beating of the lateral-line system is a function of the tissue and is not an artifact of the apparatus, certain control experiments were necessary. Mechanical changes, such as vigorously tapping the containing vessel, will produce sudden shifts in the base line with high amplification, which, while not especially resembling nerve impulses in form, may nevertheless be misleading. Lateral-line nerves were crushed and their spontaneous activity stopped. A tuning-fork was then set vibrating and pressed against the outside of the dish containing the preparation. No such effects were recorded as those seen in Fig. 3a, although sometimes slight disturbances were superimposed on the smooth base line which corresponded identically with the frequency of the tuning-fork. In fact these disturbances were photographed and used in checking the calibration of the forks. This effect was very different from that recorded in Fig. 3a.

The fact that translation of the mechanical energy of the fork into electrical disturbances did occur in the system and was transmitted to the electrodes through quite inactive nerve (a Ringer-moistened thread in contact with the fish's body would give the same result) made it seem possible that this disturbance, superimposed on the background of spontaneous activity of the normal nerve, might produce a periodic activity of the recording system, and thus account for the result seen in Fig. 3a. To examine this possibility it was necessary to find a nerve which could be made, by suitable stimulation, to give a discharge density similar to that of the lateral-line nerve. Such nerves could then be tested under the same conditions as those used in testing the lateral-lines nerves. The most suitable preparations for this purpose turned out to be the dorsal cutaneous nerves of frogs. A frog, with brain and cord pithed, was put in the same dish used for the experiments with the catfish. The level of the water was brought up so as to immerse all but the back of the frog lying ventrum down. The nerve, cut at its entrance to the cord, was drawn across the electrodes.

Fig. 3b shows a typical discharge initiated by pressing a frog's skin with a feather held in the hand. The vibrating tuning-fork (200
double vibrations) was pressed on the outside of the dish near the beginning of this discharge. No response such as is shown in Fig. 3a was found to occur in repeated experiments involving twelve dorsal cutaneous nerves. Since the experimental set-up and the massiveness of the discharge is the same in the experiments with the catfish and those with the frog, it seems safe to conclude that the phasic effects shown in Fig. 3a are produced by the rhythmic beating of the lateral-line end organs brought into "step" with each other by the vibratory stimulus. 1

From the foregoing experiments the lateral-line organs appear to be tactile receptors, a finding quite in agreement with much of the previous work, especially that of Parker. The peculiar thing about these organs is that they respond to pressure of moderate durations by an increase in frequency. For short rhythmic pulsations of pressure as produced by tuning-forks the randomly beating neuromasts get into phase with each other and beat synchronously at frequencies ranging from 20 to 70 beats per second, depending upon the individual animal, but independent of the frequency of the stimulus for forks giving 100, 200, and 250 double vibrations.

In view of the continuous activity of the lateral-line system it seemed probable that temperature might modify the activity. Despite the negative findings of both Fuchs and Parker, such modification might serve as a basis for temperature discrimination. Tests of the spontaneous activity of the same lateral-line nerve at different temperatures consistently showed marked changes in frequency with temperature. For these experiments a decapitated fish was hung tail downward in a glass jar containing water. The level of the water was adjusted so as just to cover the body up to the incision. As in all of the experiments, care was taken to keep the wound, and especially the nerve, moistened with Ringer solution. The temperature of the water in the jar was read by means of a thermometer suspended in it, and the discharge of

1 In some control experiments a massive discharge of impulses was produced by putting 10 per cent acetic acid on the frog's skin. The frog gastrocnemius was also stretched and the discharge of impulses was recorded from the sciatic nerve. Here again rhythmic effects such as are seen in Fig. 3a were never produced when the tuning-forks were applied, during the discharge, to the outside of the dish containing the preparation.
Fig. 4. Spontaneous discharge of a lateral line nerve at different temperatures.
the nerve was photographed. In addition to the spontaneous discharge, the effects of certain of the mechanical stimuli which have just been discussed were also measured. The reception of these stimuli seemed to be unaffected by temperatures ranging between 5° and 28°C. Data were obtained on the responses of ten lateral-line nerves for this range of temperatures. As soon as the suitable record had been obtained for a given temperature, the water in the jar was quickly siphoned off without moving the preparation, and was replaced by water at another temperature. This change of water could be effected in 30 seconds. A series of beakers with water at suitable temperatures was kept on hand to facilitate rapid changes of the bath. Measurements of the discharge at the new temperature were made after approximately 1 minute.

Fig. 4 shows typical spontaneous responses of a lateral-line nerve at four different temperatures. It may be seen that the frequency declines considerably when the temperature is lowered, and that it recovers fully on raising the temperature again. A quantitative analysis of the effect of temperature on the frequency of discharge is in preparation. The results are in disagreement with those of Fuchs reported in 1895, who was unable to obtain responses to changes in temperature from the lateral-line nerves of the torpedo fish. Positive results with the electrical recording apparatus then available would be unlikely if the responses to temperature changes are similar in the lateral-line nerve of the skate and the catfish. A decline in frequency with temperature would merely shift slightly the base line of an insensitive instrument, a change the significance of which might readily escape attention.

To test the possibility that the lateral-line system may be concerned with temperature reception, I endeavored to obtain impulses in response to temperature changes from spinal nerves and from branches to the facial nerves in the catfish. Marked temperature changes between the ranges of 0°C. (from ice on the skin) and 28°C. produced no nerve impulses. Some six spinal nerves chosen at random were tested

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2 By severing the lateral-line system just caudal to the junction of the nerve to the body it has recently been possible to get responses from only one organ supplied by 10-15 fibers. By chilling this preparation it is possible to silence progressively all but one fiber.
in two fishes, and branches of the facial nerves supplying in different cases the lips and barbels in three fishes were examined. The areas supplied by the nerves were in all cases carefully mapped by touching the skin with a feather and listening to the burst of impulses on the loud speaker. Water from a pipette at temperatures above or below that of the water bathing the skin was allowed to diffuse slowly onto the sensitive area. A few responses were often initially produced owing to the pressure of the diffusing water, but these stopped with the current, and were the same regardless of the temperature of the water. This negative evidence strengthens the possibility that temperature sensitivity in the catfish may be mediated by the lateral-line system which alters the frequency of its spontaneous discharge with temperature. The position of the neuromasts just under the skin, their wide distribution, not only along the lateral-line, but in the head as well, is anatomically consistent with their use as temperature receptors.

DISCUSSION

The strongest evidence against the notion of the lateral-line organs functioning as temperature receptors was presented by Parker's (1904) experiments. The behavior of Fundulus in which the lateral-line organs were non-functional was indistinguishable from that of normal fishes, at various temperatures, and Parker concluded that heat is not a stimulus to the lateral-line organs.

These results, however, do not seem to me to be conclusive. The behavior of all the fishes at any temperature was at first to go to the bottom of the aquarium and to remain there for varying periods of time. This seems to have been a sort of escape movement initiated by placing them in the vessel. During these intervals at the bottom the fish would approach the temperature of its surroundings, and its subsequent rise to the surface at certain temperatures might depend entirely upon factors conditioned by the internal temperature, independently of the activity of temperature receptors which the fish either might or might not possess. This criticism may be applied to many studies of the effect of temperature on cold-blooded vertebrates where one is concerned primarily with the problem of thermal receptors.

Certain observations, however, do indicate that fishes possess a temperature sense. The influence of temperature in determining the migratory course of sal-
mon to inland spawning waters has been pointed out by Ward (1927, 1929). The fishes swim upstream against the current, and when they come to branching streams they always swim into the colder of the two, other things being equal.

Wells (1914) has reported experiments on a variety of species of fresh water fish including the catfish. His work indicates that fishes possess a high degree of sensitivity to temperature. Fishes were put in a long, narrow tank, with water at different temperatures flowing in at the two ends. The water flowed to the middle of the tank and thence out through drains at the top and bottom. The result was a mixing of the water and the production of a temperature gradient, especially in the middle third of the tank. The fish was introduced at the center of the tank, and a graph of its movements was made. In a like manner control experiments were made using the inflowing water at both ends of the tank at the same temperature. In the control experiments the movements were of a random nature, but in the experiments with different temperatures at the two ends, all four species of fish examined, including *Ameiurus melas,* turned sharply away from the cold portions of the tank and elected to remain in water of 16–19°C. According to Wells, fishes react to variations of temperature as small as 0.1°C.

The present findings, while not proving that the lateral-line organs act as thermal receptors, do show that they may do so, since they respond to differences of temperature which other cutaneous organs apparently do not.

According to Herrick (1901) the lateral-line sense organs of *Ameiurus* are of three structural types: (1) large pit organs; (2) small pit organs; (3) canal organs. The pit organs are scattered over the skin of the flank, and are supplied by twigs of the lateral-line nerve. It is possible that one or another of these types of organs may alone be composed of direct tactile receptors, and that another type may function as spontaneously beating receptors. That this may be true is suggested by Fig. 2, especially by records (a) and (c). Here mechanical stimulation increases not only the frequency of discharge but also raises the height of the potential spikes. This could be brought about by the simultaneous discharge from several fibers or by bringing into play entirely new receptors whose nerve fibers give large action potentials. From the single appearance of the potential spikes obtained on stimulation this latter alternative seems likely. On the other hand, the increased height of the potential spikes of Fig. 3 in response to tuning-fork stimulation is apparently due to the synchronizing and summation of the discharges of the spontaneously firing fibers.

The continuous discharge of the neuromasts would hardly be ex-
pected from their structure. It is possible, however, that the hair-like filaments of the sensory cells projecting into the lumen of the canal, may actually be cilia which by beating set up a state of continuous excitability in the end organs of which they are a part. I know of no direct evidence concerning this matter, one way or the other.

The action of the lateral-line system of *Ameiurus* in inhibiting responses normally induced by mechanical stimulation of the ears and skin (Parker and Van Heusen, 1917) bears certain points of resemblance to the inhibition of tactile receptivity by the visual apparatus as described by Crozier (1918). Crozier found that the hamlet or grouper fish, *Epinephelus striatus* (Bloch), undergoes a marked increase in sensitivity to slight mechanical disturbances in the water after the exclusion of vision. The fishes were able to avoid collisions with rods and wires in an aquarium much more effectually after depriving them of vision than with the visual apparatus functioning. The visual apparatus inhibits the reception by the skin of mechanical disturbances produced by objects in the water—objects which may either be moving toward the fish or towards which the fish moves. The continuous stream of centripetal impulses from the retina evidently produces central inhibition in the centers concerned with the reception of tactual cues. The lateral-line nerve, in a state of constant spontaneous activity, produces a centripetal stream of impulses which may be compared to the impulses continuously passing over the optic nerve when light acts on the retina. The centripetal impulses from the lateral-line nerve may also produce central inhibition of incoming tactual and auditory impulses in the way that the visual impulses centrally inhibit those from the tactile receptors in *Epinephelus*. The inhibitory effects of the lateral-line system may therefore be a corollary of the spontaneous activity.

The responses of the lateral-line organs to movements of the fish's trunk are interesting, since they may serve as kinesthetic cues in swimming. These impulses may act to regulate speed of swimming and direction of turning, especially in darkness and when the fish is in midwater.

SUMMARY

1. Records of impulses from the lateral-line nerves of catfish show that the lateral-line organs are in a state of continuous activity, producing a massive discharge of impulses.

2. The discharge may be increased during the direct application of pressure on the skin over the lateral-line canal, by ripples in the water, by irregular currents of water, and by movements of the fish's trunk.

3. The asynchronously discharging lateral-line organs respond to
vibratory stimuli from tuning-forks by getting into phase with each other and by beating synchronously at frequencies ranging from 20 to 70 per second. The frequency of beating for a given preparation is independent of the frequency of the tuning-fork for the fork frequencies of 100, 200, and 250 double vibrations which were used.

4. The continuous discharge of the lateral-line system is markedly changed by alteration of temperature. The frequency declines on lowering the temperature and rises on increasing it. Spinal and facial nerves in the catfish fail to yield nerve impulses in response to changes of the skin temperature between 0° and 28°C., although the intact animal is known to be sensitive to temperature differences.

5. The action of the lateral-line system of *Ameiurus* in inhibiting responses initiated through the skin and ears (Parker and Van Heusen, 1917) is discussed in the light of the present experiments.

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