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ELECTRIC TRANSMITTING ORGANS AND DETECTION
PROCESS HYPOTHESES IN ELECTRIC FISHES

4 February 1974

Most authors and scholars of electric fishes agree that:

1. The anatomy and physiology of the electric organs of different species are diverse;
2. The diversity among species strongly suggest that the electric organ-electroreceptor system plays quite different roles in the biology of different species. But what is this role is not known as of today;
3. Some classification has been made with regard to their transmitting electric organ as follows:
 - a. low resting frequency, high standard deviation of interval lengths and responding to different kinds of stimuli with a many-fold increase in frequency and amplitude of the signal (for example, Gnathonemus petersii),
 - b. medium resting frequency, medium standard deviation of interval lengths, responding to some stimuli with a several-fold increase in frequency (for example, Gymnotus carapo),
 - c. medium frequency with little or no change in the repetition rate of the signal, but with the possibility to stop completely the discharge (for example, Gymnarchus niloticus),

- d. high resting frequency with low standard deviation, responding to a few special stimuli with small shifts in repetition rate of the signal (for example, Sternarchus albifrons),
 - e. species with no known response to stimuli with change in the repetition rate of the signal.
4. The discharge of the electric organ has been found to be commanded from a pacemaker center in the medulla, in most species studied until now. (See Fig. 1.) This train of impulses seems to be relayed 1:1 in a nucleus in the medulla and again in the electromotor neurons in the spinal cord to be passed through the spinal nerves to the electric transmitting organ.

Some electric fishes have a very elaborate array of electroreceptors. All electric fishes have other sensory receptors mostly part of the lateral line system like: temperature receptors, mechanical receptors and water-displacement receptors. These sensory receptors are located in the dermis. There are other sensory receptors non-related to the lateral line like: acoustical receptors, chemical receptors, olfactory receptors, taste receptors and in some electric fishes optical receptors (vision); not to mention equilibrium and stabilizing receptors.

All these sensory receptors, electric and nonelectric, may work separately or in accordance in a hybrid cross correlation information system used in social interaction, feeding, swimming and navigation, in offense or defense. Because of the multiplicity of use the sensory system is very complicated using neuronal preprocessings and discriminating filtering systems, delay-lines, etc.

Some electric fishes use passive and/or active object detection systems. There are some marine and fresh-water fishes which do not have any electric transmitting organ, but have an electroreceptor system. (Marine sharks like:

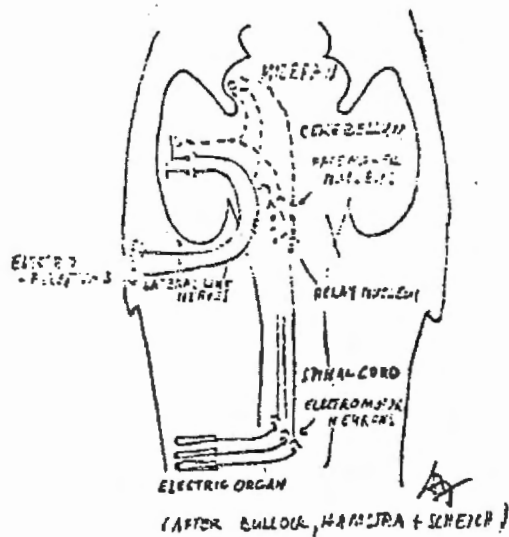


Fig. 1. Connection between the pacemaker in the brain, the relay nuclei, the electromotor neurons, the electric transmitting organ and the electroreceptors in electric fishes.

Negaprion brevirostris, Scilliorhinus canicula, a catfish: Plotosus or the eel Angrilla anguilla and freshwater fishes like Clarias.)

A classification of electroreceptors can be made from the following criteria:

1. Autorhythmic. This means that they emit a very low amplitude signal from less than one to a few millivolts. Depending on the particular receptor class it can have a low repetition rate (less than 100), a medium repetition rate (from 100 to 500) or a high repetition rate (from 500 to 3000),
2. Nonautorhythmic.

or we can divide them in:

3. Synchronous. This means that they respond to the transmitting organ in case of a stimulus with a nerve transmission spike rate synchronized to the electric organ.
4. Nonsynchronous.

Another classification could be used as:

5. Ampullary organs similar to or identical with the Lorenzini ampulla which has a canal lined with a very high resistance membrane filled with a jelly and communicating to an ampulla with sensory organs. The jelly can be high, medium or low conductive and accordingly being acid, neutral or basic. There are many kinds of sensory cell formation classes.
6. Tuberos or mormyromasts, mostly not directly connected to the surface of the skin. Every mormyromast may have one, two or more sensory cells separately innervated and responding each to different amplitudes (levels) of stimuli.

Maybe a more adequate classification would be one taking into account the stimuli to which these electroreceptors respond such as:

- a. Conductivity: conducting or nonconducting objects, the level of response being more or less proportional to their conductivity factor;
- b. Direction: response of the sensory cells being conditioned to the fact that an object is directed toward or away from the fish;
- c. Form: sharp edges will stimulate some receptors, others will be stimulated by round or rounded objects;
- d. Movement: the change in position or form of an object will produce a modulation of the autorhythmic impulses of some receptors and will be sensed by the fish;
- e. Smoothness or Roughness of objects could also constitute a criteria of stimuli classification;
- f. Chemicals in the water may affect the electric receptors and their response, we have proof for this.

Finally coding can be a classification criteria. Lissman and Machin proposed a

1. "Pulse-frequency-modulation" (like in Gymnarchus niloticus);

Watanabe and Bullock proposed a

2. "Pulse-phase modulation" (like in Eimannia virescens);

Szabo and Hagiwara analyzed and suggested three other kinds of codings:

3. "Number coding mechanism" (like in gymnotids as: Hypopomus artedi),
4. "Probability coding mechanism" (like in gymnotids as: Sternarchus albifrons),
5. "Latency coding mechanism" (like in mormyrids as: Gnathonemus petersii).

According to the first hypothesis "Pulse-frequency modulation" sensory information should be conveyed by the frequency of the sensory impulses dependent on the pulse of the electric discharges.

The second hypothesis "Pulse-phase modulation" the sensory coding is the result of time relation (the phase) on the sensory impulse following the electric organ discharge.

The third hypothesis called the "Number coding mechanism" supposes that the intensity of the electric potential field is coded through a single electroreceptor fiber by the number of nerve impulses produced by each electric organ pulse.

In the number four hypothesis, called "Probability coding mechanism," the coding is provided by the probability that each electric organ impulse might initiate an impulse in the nerve fiber.

Finally the fifth hypothesis: "Latency coding mechanism" is explained by the fact that certain mormyrid electroreceptors permit a change in latency of impulses of the electric organ related to the intensity of the current flowing through the receptor. Therefore, the intensity of the potential field can be coded by the time relation between electric transmitting organ discharge and sensory impulse, the time ranging being as much as 8 milliseconds. For variations in the superthreshold field intensity this would be the only mechanism for a sensory organ producing single spikes. The place where the latency-shift of the sensory impulse is taking place has not as yet unequivocally explained.

It is worth mentioning that there are electroreceptors connected to nerve fibers which would not transmit any impulses without a specific stimulus. Other electroreceptors are related to nerve fibers discharging continuously.

Some, when presented with stimuli, would increase their electric activity and others would decrease it.

The first type of fibers are called phasic fibers, the second type are called tonic fibers. Electroreceptors connected to phasic nerve fibers are called phasic electroreceptors (i.e., tuberous organs = mormyromasts); electroreceptors connected to tonic fibers are called tonic electroreceptors (i.e., ampullary organs like the Lorenzini ampulla).