the major contributing factor in CSF was calcitonin[7], a naloxone-resistant analgesic peptide[10]. The present findings, however, suggest that opiate substances, which were also high in the CSF of this patient, may play an important role in determining pain insensitively as well. It is possible that we and the others[12] could have observed a naloxone attenuation of pain indifference if higher doses or chronic drug regimen had been employed. Further experiments are in progress to evaluate the possible benefits to our patients of a more prolonged naloxone therapy.

While some of the analgesic substances in the CSF of our patient as well as in the patient described by Dunger et al[6] are opiate-like, they are apparently neither beta-endorphin nor met-enkephalin[6,8]. Instead, they are probably one or more of the numerous endogenous opioid peptides so far described[14]. These findings offer further support to the idea that congenital indiffernece to pain might be considered to be an endogenous analgesic peptide disorder in which a patient is excreting abnormally high levels of opiate as well as non-opiate analgesic substances.

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Electroreception in the Turkistan catfish

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Summary. The Turkistan catfish, *Glyptosternum reticulatum*, has highly sensitive electroreceptors (threshold voltage gradient 1 μV/cm) that detect a voltage drop across the skin. These electroreceptors were found to be sensitive to magnetic stimulation.
Key words. Catfish; electroreceptors; skin; magnetic stimulation; siluriform fishes; lateral line organ.

The presence of specialized electroreceptors within the lateral-line organs of siluriform fishes (order Siluriformes) has been demonstrated in various kinds of experiments. Until recently the species of only 10 families of this order (Clariidae, Saccobranchidae, Siluridae, Malapteruridae, Ictaluridae, Pimelodidae, Doradidae, Loricaridae, Gallichthyidae, Plotosidae) were known to have the electroreceptor apparatus[1-4]. We believed that other siluriform fishes might also be electroreceptive, therefore we carried out experiments on the Turkistan catfish *Glyptosternum reticulatum* (Sisoridae, Siluriformes), which lives in the rivers of Soviet Central Asia.

In our experiments single unit activity was recorded from the lateral-line nerve innervating the receptors of the caudal part of the body. In every case, the peripheral portion of the cut nerve was placed on a dark Perspex dissecting plate which contained Ringer solution, and the nerve sheath was carefully removed. The nerve was then divided into very fine strands under a dissecting microscope. Nerve activity was recorded in filaments which contained only one active fiber with silver hook electrodes. The nerve impulses were amplified and displayed by conventional means[5,6]. To stimulate the sensory organs, homogenous electric fields were used. Direct current pulses were applied from DC stimulator via a high series resistance through 2 silver electrodes. In addition, electroreceptor responses to magnetic stimulation were investigated. Magnetic stimuli were produced by a constant bar magnet that moved horizontally in the air at various distances above the fish. To measure the skin electrical properties, the isolating ring with 15 mm in diameter was placed on the skin above the water level (fig. 2c). The skin around the ring was rinsed with distilled water and dried with filter paper to prevent electrical leakage from the ring. The skin potential was recorded by means of an electrolytically chlorided silver wire electrode (E_1), which was placed inside the ring. The ring was filled with water. The reference electrode (E_2) was a chlorided silver wire introduced into the body. DC current pulses (10^{-8}–10^{-6} A) were supplied from DC stimulator to the isolating ring through the silver electrode (E_3). the skin potential and its changes were recorded via an impedance of 10^8 Ω by a pen-recorder. The skin resistance was estimated by the voltage drop across the skin; the

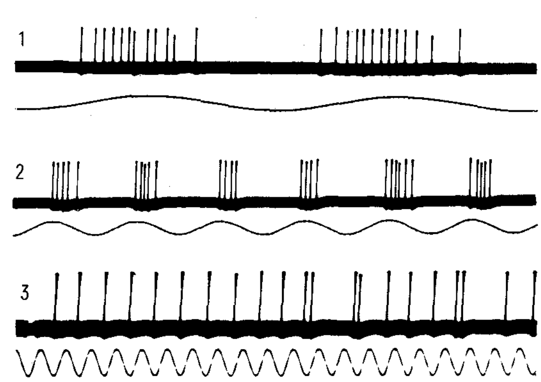

Figure 1. Responses of a single Turkistan catfish electroreceptor to application of a sinusoidal electric field.
Voltage gradient 15 μV/cm. Frequency of stimulation 1(1), 3(2) and 10(3) Hz.

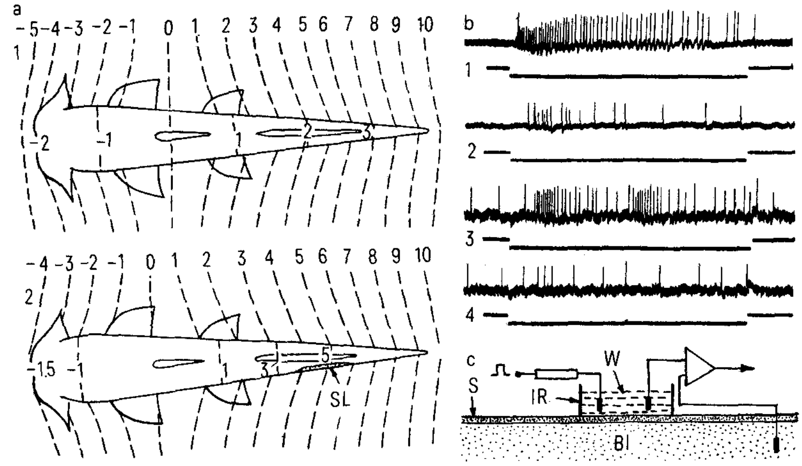

Figure 2. Effective stimulus for electroreceptors of Turkistan catfish. *a* Structure of electric field outside and inside the fish body before (top) and after (bottom) damage of the skin. SL, wound on the skin. Dashed lines, isopotential lines of the field. Figures denote arbitrary units of potential. *b* Influence of the skin damage on the responses of nearby electroreceptor. 1, Responses with intact skin; 2, after the skin lesion; 3, after the wound insulation with vaseline; 4, after removing the insulation (vaseline). Stimulus duration 1 sec. *c* The experimental set-up for measuring electrical properties of the skin. IR, Isolating ring; W, water within the ring; S, skin; BI, body interior.

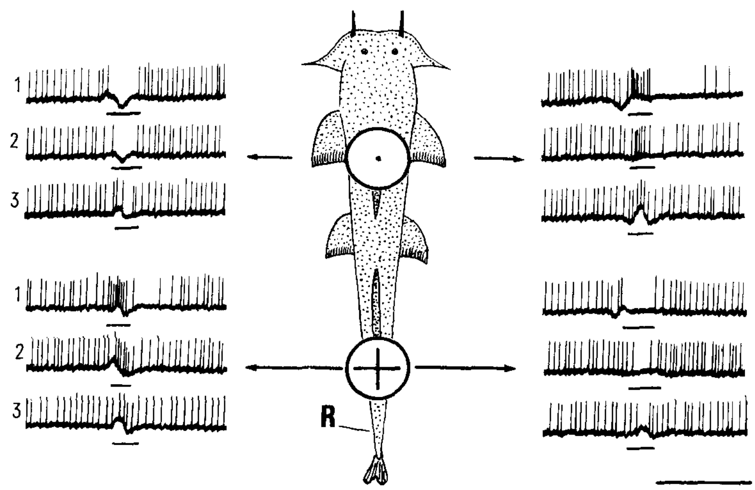

Figure 3. Responses of single electroreceptor to stimulation with vertical magnetic field. Arrows indicate directions of a magnet moving. Corresponding to these directions receptor responses are presented for ventrodorsal (top) and dorsoventral (bottom) magnetic field. Horizontal bars correspond to a magnet moving. Magnetic induction 186(1), 23(2), 2.9(3)$\cdot 10^{-4}$ T. Speed of moving is 1 m/sec. Deflections of the zero line-artifacts of the magnet moving. Time bar-500 msec. R, Electroreceptor under study.

skin capacity was determined by the time constant of the potential change.

Our experiments showed that the Turkistan catfish possesses electroreceptors with the same sensitivity as those of the freshwater electrosensitive fishes previously studied. The least voltage gradient in the water that caused the visible spike frequency reaction of the receptors was about 1 μV/cm (the water specific resistivity 4 kΩ·cm). As a rule the afferent fibers arising from the electroreceptors were spontaneously active at frequencies of 5–30 imp/sec. Electrical stimulation caused spike frequency changes typical for ampullary electroreceptors of teleost fishes. In other words, anodal stimuli (positive at the receptor opening) evoked an increase in the discharge frequency after 10–50 msec latency and cathodal stimuli decreased the impulse frequency. For the long-lasting stimuli of either sign there was an adaptation with a time constant of about 10–15 sec. The optimal frequency of stimulation was 1–3 Hz (fig. 1).

The study of electric field structure showed that voltage gradient in fish body interior was much smaller than in surrounding water due to relatively large skin resistance coupled with the low internal resistance (fig. 2a). Consequently, at every skin point far enough from the zero-isopotential line there was a voltage drop across the skin that served as an effective stimulus for electroreceptors. Skin damage that short-circuited the transskin resistance drastically reduced the sensitivity of nearby electroreceptors (cf. figs 2a–2 and 2b). The resting transskin potential was in the range of +8 – +20 mV (outside vs inside). The resistivity and capacitance of the skin were 20–30 kΩ·cm^2 and 1 μF/cm^2 respectively.

In these experiments we demonstrated for the first time the spike frequency responses of a freshwater fish electroreceptor to magnetic stimulation (fig. 3). The largest responses were observed when a constant magnet moved in the direction perpendicular to the fish's longitudinal axis. The first noticeable reaction was observed with magnetic induction of 2.9×10^{-4} T when the magnet moved with a speed of about 1 m/sec. The sign of receptor response to magnetic stimulation was in agreement with Faraday's law of induction; with ventrodorsal direction of the magnetic field caudal receptors were excited when the magnet moved from the left to the right (the vector of the induced electric field directed from the tail to the head in this case).

The results of the experiments showed that the Turkistan catfish has highly sensitive electroreceptors that may be involved in prey detection and reception of other biologically important information. One might expect to find that electrosensitivity is a common property of all species of siluriform fishes.

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