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Electric fish and sensory feedback

Ottawa partners seek answers on human sensations Neuroscientist and physicist pool their research resources

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OTTAWA- A large question and a tiny fish brought Leonard Maler and Andre Longtin together from the disparate scientific disciplines of neuroscience and physics.

The large question was how the human nerves and brain manipulate the flood of signals delivered by our eyes, ears and other senses to be able to understand our surroundings.

"What are the grand organizing principles?" asks Longtin.

"What does each cell care about out of all the stimuli that impinge upon it?"

Tackling that question brought Longtin, the physicist, to Maler, a neuroscientist colleague at the University of Ottawa, and together led the duo to a wiggling denizen of the Amazon River - the brown ghost knife fish, known scientifically as Apteronotus leptorhynchus.

By understanding the sensory codes used by the knife fish to distinguish a tasty insect from something like a pebble in the murky Amazon, Maler and Longtin hope to take a first step toward unravelling the similar but much more complex coding of sensations that takes place in humans.

Eventually, this knowledge could help in designing an implant to restore sensory feedback damaged by brain tumours or lead to prosthetic devices to generate more realistic sounds for the hearing impaired, a subject currently being investigated by one of their graduate students.

Right now, however, the two researchers are concentrating on expanding an unusual intellectual partnership that began in 1994 and was honoured last week with the University of Ottawa's first award for interdisciplinary research: $25,000 in extra research funding.

The partnership centres on a tapered, unprepossessing animal not much longer than the average ballpoint pen: the brown ghost knife fish, which can barely see or smell.

Home aquariums are more likely to hold the somewhat showier black or transparent varieties, but all two dozen varieties of the Apteronotus - including the drab brown - are electric.

They "see" by generating electricity internally and measuring how their own electric fields are distorted by whatever is in their vicinity.

"People put them in aquariums and don't realize what big brains they have and that they're communicating all the time," says Maler.

That communication is made possible by a weak electrical discharge from nerve cells in the fish's tail that act like batteries, with males sparking between 800 and 1,000 times a second and females between 600 and 700.

Maler compares that output to a high-frequency heart pacemaker.

"Most of the metabolic energy of the fish goes into making this high-pitched discharge, so it has to be very central in its existence," says Maler of his tiny subject.

Apteronotus has adapted to use this discharge for communication with other knife fish and for scanning its surroundings.

Arrayed along the surface on both sides of the fish's body, with the greatest concentration around the head, are 16,000 special sensory cells that continually measure the surrounding electric field, a bit like a home battery tester.

When the electric discharge from the tail comes up against an object like a stone or aquatic insect, the run-in causes a change in strength or frequency that is picked up by the surface detectors.

The computer-generated image on this page illustrates how a tiny water flea would be instantly detected when its body disturbed the electric field.

Sensory systems in animals are used not only to analyze the environment - like a bird detecting wind in the trees - but also to analyze communications, as in birdsongs.

Because these two functions are complex and intertwined, they are mostly very difficult to study. But that's less of a problem with the brown ghost knife fish, because its external electrical signals are simple to measure and to manipulate.

Says Maler: "It's easy to spy on these guys."

Consider the aggressive territorial nature of Apteronotus leptorhynchus.

When two males meet, there's usually a physical tussle until one is routed. But there's also electrical communication, with the normal steady buzz from the fish interrupted by two or three brief, higher-pitched "chirps" every second.

To unlock what Longtin calls the "Holy Grail of a sensory code," the researchers must sort out which stimuli the fish's neurological system pays attention to and which it ignores.

The trigger could be a high-frequency signal followed by a lower one, or how quickly signals change, or the size of the fluctuation.

In this quest, a big plus is the nature of the brown ghost knife fish's hindbrain. Like the human brain, it has a layered structure, but it's a lot simpler - with only six different types of cells versus our 60 types.

"The circuitry is accessible," notes Longtin. "We can record the currents there."

Another important parallel is a protein known as the NMDA receptor. In the human brain, it mediates how cells connect and pass along an important type of excitatory signal.

Maler found a piscine version of the NMDA receptor in Apteronotus, very similar to the human protein despite the hundreds of millions of years that have passed since fish split from mammals on the evolutionary tree.

"In the fish, the NMDA receptor is responsible for what you might call online adaptation - like how your senses adjust when you walk from inside a dark building into bright sunlight," says Maler.

"Finding it in the hindbrain of the fish is very encouraging."

Despite such advances, the University of Ottawa researchers still face a daunting slog to reach their ultimate goal of making sense of all the neural firing patterns in the fish, including the mysterious role played by feedback.

Their hope is that some of the sensory encoding in the fish will also apply in people.

Longtin and Maler say they never would have progressed this far without the blending of knowledge that each brought from their scientific disciplines of biophysics and neuroscience.

They shared a mutual interest in experimental neurobiology and in the training of computational neuroscientists. But initially they didn't speak the same language, with even a word seemingly as simple as "noise" having different connotations in their respective fields.

"We had to become conversant in each other's concepts, in the folklore of each other's fields," says Longtin.

The partnership really gelled when the professors began supervising graduate students together.

Says Maler: "Our students speak both our languages. They look at biological problems from a math and physics point of view."

And that may be the only way to answer the large question represented by a tiny fish.'People put them in aquariums and don't realize what big brains they have'

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