A Shark's Sixth Sense

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In honor of the Discovery Channel's Shark Week, we're taking a look at the electrifying capabilities of sharks and fish that help them find their way (and even their dinner)!

Resident expert Malcolm MacIver, assistant professor of biomedical engineering at Northwestern University's McCormick School of Engineering, explains.

We usually think that electricity and water don't mix, but I hear that some underwater creatures use electric signals to navigate or find food. Is this true?

You're correct—certain kinds of fish and other animals, like sharks, can use electric signals to detect objects. This is called electrolocation. There are two forms of electrolocation, active and passive. It's like the difference between sensing something with radar, which is active, versus just listening to something, which is passive.

How does active electrolocation work?

Using active electrolocation, an animal emits a weak electric field, allowing it to sense the presence of nearby objects without actually touching them. It works in the following way: if you have a fish in a fluid, let's say fresh water, that fluid has a certain electrical resistance to it. If you put an object in that fluid with a different resistance, like another animal, it creates a distortion in the water's electrical properties. The fish's active electrosensory system detects this distortion. This ability does not extend more than a body length away, but it's very effective in that short range.

For example, on the South American freshwater electric fish I research, the black ghost knifefish, there are about 17,000 receptors covering the entire body surface. All of those sensors are like little volt meters that are picking up distortions around 1.0 – 0.1 microvolts, a millionth of a flashlight battery in voltage, caused by any objects that might be in their sensory range.

How does passive electrolocation work?

Other animals, like sharks, don't generate their own electric field. Instead, they have sensors that can pick up electric signals, which are created by every living animal in the water. This is passive electrolocation. When you go into the ocean, you have what's called a bioelectric potential around your body; sharks can hone in on that using electroreceptors. Any kind of cut in the skin increases this bioelectric potential, creating a sort of electrical spotlight and putting the animal at a higher risk of being detected. We know that sharks hunt using their extremely sensitive sense of

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smell as well – but this is mostly useful for getting in the general vicinity of potential prey. Passive electrolocation complements this blurry sensory ability so that the shark can make a precise attack.

Do sharks also use electrolocation to navigate? And if so, why?

We know that sea turtles are able to pick up both the direction and intensity of the earth's magnetic field. If you chart these two factors across the globe, in certain places you actually get a very nice bi-coordinate map – like longitude and latitude but in terms of the intensity and direction of the magnetic field. We have determined that they're able to navigate by these fields. We don't know exactly how, but we know that if we put them in a tank with big magnets, we can confuse them in predictable ways.

We don't know if the same is true for sharks. However, there's some behavioral evidence in support of the idea—for example, they go long distances in straight lines consistent with following the earth's magnetic field when there appear to be no other cues available. What we do know is that sharks have this amazing ability to sense external electrical fields such as bioelectric fields. Their sensitivity is astonishing – it's on the order of a nanovolt. If you put a flashlight battery in the ocean, there's about a nanovolt every inch or so more than a mile away from that battery. That sensitivity is almost hard to believe. It's high enough that they can detect the direction and intensity of the earth's magnetic field by sensing the internally induced currents that happen when they move through it.

Why would they need a sensory ability like this? Picture yourself out on the ocean. There are a ton of cues indicating direction—direction of polarized light, wind and wave direction, water current direction, even where bright stars are at night. The problem for a shark is that they're way, way down and they want to go a long distance. One great white shark, which was tagged with a transmitter, was shown to go from Africa to Australia and back – over ten thousand miles! So how are they going to do that without any of these things like polarized light direction or wave cues? Although far from being settled, some scientists suspect that sensing the earth's magnetic field using their electrosensory system is one trait sharks have developed to get from one place to another in the absence of other navigational indicators.

What are some of the long-term practical applications of robotics research in sharks and weakly electric fish?

Quite a few, actually. So it turns out that sensing by way of electric fields – in the way that fish do this – is relatively unexplored in engineering. If we understood how that works, we could potentially have a whole other sensory modality to work with.

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For example, if you are a roboticist who wants to bring robots into everyday home life, the number one problem you'd be trying to solve is the problem of manipulation. What do I mean? I mean gripping something. Picking something up like your newspaper, handing it to a person. Picking up a cup of coffee. That stuff is really, really hard for robots. It's a tough problem to solve.

Robots have contact sensors, which are good once you touch something. But what humans do, when we approach something to grab it, is pre-shape our grasp based on visual cues—we actually manipulate our hand so it is at least in the right general shape. Active electrolocation could allow robots to sense the shape of an object before touching it, bridging this sensory gap.

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