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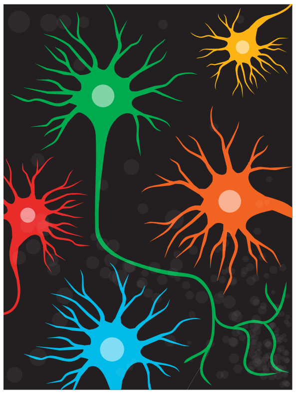
OUTSIDE JEB

Touchy-feely fish fins



It's late and you're stuck in the office. Suddenly, the power goes out and you're plunged into darkness. How do you navigate in this low-light environment? The reflex response is to stick out your hands and feel your way around. The bumpy edge of your keyboard, the smooth surface of your desk, the cool roundness of the door knob: our fingertips can convey a lot of information about our surroundings. Turns out, we may have our fish cousins to thank for this fine-tuned sense of touch. Fish may not have fingers, but they certainly aren't without feeling!

It's no surprise that fins transmit information like movement and position relative to the body (i.e. proprioception) back to the fish brain. However, Adam Hardy and colleagues from the University of Chicago, USA, wanted to see whether more detailed information about the environment could be sensed by fleshy fin membranes. The difficulty in addressing this question lies in the principal role of most fish fins, which is to get around. As touch is distinct from the proprioception experienced when swimming, the researchers needed a fish in which they could easily distinguish between these two senses. Their best bet was to find a species that might rely on a heightened sense of touch to survive, but which doesn't use all of its fins to swim. Luckily, they came across the pictus catfish, *Pimelodus pictus*. This bottom-dweller spends its life lurking in the murky Amazon River. The catfish possesses a serrated spine along the front edge of its pectoral, or 'arm', fins, which it can lock into place and use for defense. The rigidity of this spine means the catfish pectoral fins are useless for swimming. However, the rest of the fin is made up of soft rays and membranes, which it drags along the riverbed. Hardy wondered whether this combination of ridged front edge and soft rays allows the fish to feel its way around.

The team first used high-speed cameras to film live fish swimming. Once they confirmed that the pectoral fins are not used for movement, they examined the neural architecture of these fins by counting the density and types of sensory cells found in the soft tissues. Finally, they stimulated the fish's pectoral fins with a variety of different motions, speeds and pressures, and measured the activity of neurons sending information back to the brain.

Hardy and his colleagues found that catfish pectoral fins are packed with a dense network of sensory fibers, which resemble the Merkel cells responsible for touch in humans. Interestingly, these neurons transmit information about both the applied pressure and motion of the stimulus back to the fish. The team suggests that catfish pectoral fins function like fingers: by dragging their fins along the riverbed, the fish gain important sensory information about their habitat through touch.

Feeling your way around underwater is probably most helpful if you're living close to the bottom in dim environments, like catfish. The team also proposes that our sense of touch may have evolved much earlier in our evolutionary history than previously thought. In essence, fish and humans might experience similar sensations when touching slippery river rocks or soft clumps of algae. Now, how does that make you feel?

10.1242/jeb.130138

Hardy, A. R., Steinworth, B. M. and Hale, M. E. (2016). Touch sensation by pectoral fins of the catfish *Pimelodus pictus*. *Proc. R. Soc. B* **283**, 20152652.

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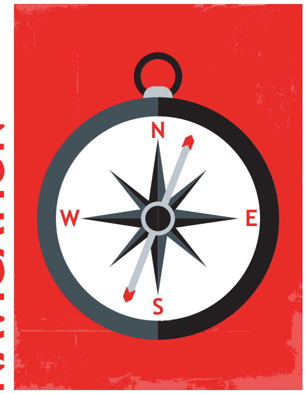
Amphibious fish prop up when seeking water



A fish out of water is commonly considered a bad thing. But for some intertidal fish, moving over land from one body of water to another is not only good, it's essential for life. Intertidal fish can find themselves submerged in water during high tide but exposed to air or toxic water during low tide. Often, these fish have physical, physiological and behavioral adaptations that allow them to safely spend variable periods of time on land, while seeking out more pristine pools. The well-known mudskipper moves around on land by hopping on its belly using its flexible muscular body and tail. The perhaps less-well recognized mummichog (*Fundulus heteroclitus*), a small slender intertidal fish, spends less time outside water than the mudskipper and has fewer amphibious adaptions. Instead of skipping on its belly, the mummichog launches across land on its side like a spring-loaded rocket. It bends its head over its body toward its tail then pushes off the ground – boing! – and propels itself backwards.

Though the mummichog's fish-rocket behavior has been previously documented, Noah Bressman, at Cornell University, USA, and other North American colleagues were curious how these fish found the water that they were seeking. Had they memorized the lay of the land, as some researchers suggested, or did they use light cues, as insects have been shown to do?

Outside JEB is a monthly feature that reports the most exciting developments in experimental biology. Articles that have been selected and written by a team of active research scientists highlight the papers that JEB readers can't afford to miss.

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The authors brought mummichogs from the wild to the lab and used high-speed video to track the fish as they moved around out of water. They placed the fish on a table with seawater on one side and buckets on the other three sides under two experimental conditions: light on one side of the table or with the room in darkness. The researchers then placed crinkled foil over the seawater in the lit room to see if the fish would navigate toward the reflected light, even in the absence of an aqueous cue.

Although many of the fish-rockets never made it off the table, ones that did preferentially moved toward the seawater and foil, under light conditions. However, under dark conditions, fish did not show a preference to move in any particular direction. As the fish had not previously encountered the lay of the lab, it appeared they were using visual cues, the reflection of light off water and foil, to navigate.

To support this finding, the authors also discovered that mummichogs would prop themselves into an upright position, lying on their bellies, in between jumps and when they were not wriggling, to reorient themselves to achieve their desired trajectory. The discovery that mummichogs prop themselves up was a first for this species. However, propping has been noted in slightly different forms in other intertidal fish and the authors suggest this behavior is crucial to enable amphibious fish to survey their surroundings.

Bressman and colleagues hypothesize that mummichog eyes are likely not well adapted to see clearly out of water. They may not be able to focus images, although it appears clear from this study that they are able to catch reflections of light and use those cues to move towards water. And the authors suggest that even though mummichogs are not as well adapted to land as belly-skipping mudskippers, the propping-before-rocketing behavior is an indication that propping to perceive is a necessary navigation adaptation of amphibious fish.

10.1242/jeb.130146

Bressman, N. R., Farina, S. C. and Gibb., A. C. (2016). Look before you leap: visual navigation and terrestrial locomotion of the intertidal killifish *Fundulus heteroclitus*. *J. Exp. Zool. A* **325**, 57-64.

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Predators prevent brain cell proliferation in wild prey

From spikes and shells to toxic defences, many species have striking traits to help them avoid becoming someone's dinner. But predators can affect prey physiology in more subtle ways. In the lab, simply living alongside predators can inhibit brain cell proliferation. We don't really understand why this is and, until recently, it wasn't even clear how predators affect brain development in wild animals. Perhaps in nature, predators provide the stimulating environment that promotes brain cell proliferation, rather than inhibits it? To test this idea, Kent Dunlap and colleagues studied wild populations of the weakly electric fish *Brachyhypopomus occidentalis.* The team asked how predation density, near misses with hungry catfish and the stress of capture affect brain development.

Brachyhypopomus occidentalis lives in rivers in Panama alongside electro-receptive predatory catfish. To see how life in risky environments affects brain structure, Dunlap and colleagues measured cell proliferation in different brain regions in fish from populations with varying levels of predation. The team also assayed plasma cortisol levels to see whether this might help explain any differences in brain structure. Fish living alongside more predators had fewer proliferating cells in their forebrains. Clearly, living under the high threat of predation affects brain development.

To see whether a close encounter with a predator had more pronounced effects on brain development, the team compared cell proliferation and cortisol levels in intact fish and in fish with nibbled tails. They found that injured fish had lower levels of forebrain cell proliferation than intact fish.

The reduced proliferation in nibbled fish might suggest a trade-off between making new brain cells and repairing damaged tails. Alternatively, the stress of capture itself might cause these effects. To see how capture affects brain structure, the team assayed fish euthanized a few minutes after collection from the river and fish euthanized after a few hours of being held in a bucket. Even this brief window of stress reduced brain cell proliferation.

These results show that living alongside predators and the injury and stress caused by predation affect brain development. However, these effects were not driven by cortisol, which did not vary consistently between fish as a function of predation risk. If not cortisol, what mechanisms could induce these effects? The stress of living alongside predators may have direct physiological effects on brain cells or predators may restrict prey behaviour and keep them away from environmental stimuli that trigger brain development. Whatever mechanisms are responsible, it is unclear whether reduced cell proliferation is always a bad thing. Brain cell proliferation may improve how well fish learn and remember but this, in turn, might favour risky exploratory behaviours. If reduced cell proliferation makes fish more cautious, then this may improve fish survival despite reducing cognitive capacity. Dunlap and colleagues show us that we can address these exciting outstanding questions in the wild as well as in the lab to really understand how predation pressure affects behaviour and physiology in prey.

10.1242/jeb.130120

Dunlap, K. D., Tran, A., Ragazzi, M. A., Krahe, R. and Salazar, V. L. (2016). Predators inhibit brain cell proliferation in natural populations of electric fish, *Brachyhypopomus occidentalis*. *Proc. R. Soc. B.* **283**, 20152113.

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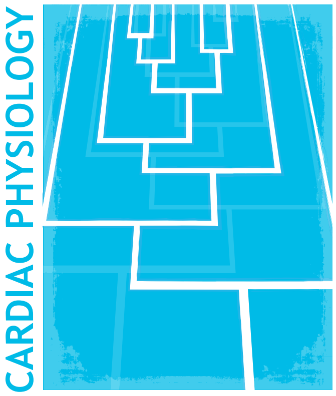
Taurine tunes cuttlefish cardiac output



In parallel with vertebrates, cephalopod molluscs (octopuses, cuttlefish and their kin) have evolved a 'closed' circulatory system, composed of pumps and pipes, that more closely resembles our own cardiovascular system than the unplumbed ('open') circulations of other invertebrates. During their evolutionary path, cephalopods have also acquired several cardiovascular peculiarities, including possessing three hearts, two of which are dedicated to supplying blood to the gills (the branchial hearts), and one (systemic) heart that pumps blood around the body. Nevertheless, cephalopod hearts share common building blocks with those of vertebrate hearts, so by investigating the cardiac physiology of these molluscs, it may be possible to reveal the foundations of heart function in animals.

Like vertebrate hearts, cephalopod hearts must be tuned to the metabolic demands of the animal, but very little is known about how this may be achieved. In a recent study, Tyson MacCormack and a team of researchers based in Canada and Portugal decided to investigate the compound taurine. Taurine is an amino acid that accumulates in tissues throughout the body and exerts diverse physiological effects in a wide range of organisms. In mammals, it elicits complex effects on the heart: it increases contractility when extracellular calcium levels are low, but at high calcium concentration (as is typical in cephalopod blood) it decreases contractility. In addition, it boosts oxygen consumption and glucose usage of mammalian heart muscle. MacCormack and his colleagues knew that the amino acid had been detected at strikingly high levels in the blood of their chosen cephalopod species, the cuttlefish (*Sepia officinalis*), so they investigated the impact of taurine on both cardiac mechanical performance and metabolism.

The team developed a method in which the systemic heart was perfused by tubes containing artificial cuttlefish 'blood', allowing them to continuously monitor cardiac output (the amount of blood pumped per minute). Having confirmed that the cuttlefish heart was functioning normally, the authors applied taurine to it and the cardiac output halved – as they had expected, knowing that the amino acid decreases contractility when calcium levels are high in mammals. The team then refined this discovery in the next series of experiments, which examined the force production of isolated muscle from both the systemic and branchial hearts. Here, taurine impaired cardiac muscle relaxation, at least when the muscle was electrically stimulated to contract at high rates. Together, these results showed that taurine can considerably depress contractility in the cuttlefish heart, similar to its role in the mammalian heart.

When MacCormack and his colleagues measured the effects of taurine on oxygen consumption in systemic heart muscle, they did not see an obvious impact, although they observed that taurine doubled glucose usage. As this latter effect is similar to that previously reported in mammalian hearts, it suggests that some of the metabolic modulations provided by taurine may have evolved deep in evolutionary history.

By studying an invertebrate, MacCormack and his team provide a refreshing context in which to understand cardiac evolution. Taurine has complicated actions on the heart, and it seems that some of these effects may well be shared across the animal kingdom.

10.1242/jeb.130153

MacCormack, T. J., Callaghan, N. I., Sykes, A. V. and Driedzic, W. R. (2016). Taurine depresses cardiac contractility and enhances systemic heart glucose utilization in the cuttlefish, *Sepia officinalis*. *J. Comp. Physiol. B.* **186**, 215-227.

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