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OUTSIDE JEB

Tired fish just keep swimming

If you have ever 'felt the burn' after intense exercise, chances are you've experienced the build-up of lactic acid in your muscles as they run low on oxygen. For most of us mammals, simply having a good sit down and a breather will help us to remove the excess lactic acid. But if you happen to be a shark, your post-workout routine is a little more energetic. Gil Iosilevskii from the Israel Institute of Technology, and a team of colleagues including Nicholas Payne from Trinity College Dublin, Ireland, noticed something odd about the behaviour of large marine fish released after prolonged capture for scientific study. These fish, far from taking things easy after their tiring experience, appear to do the opposite: they swim off at high speed for several hours. Iosilevskii and Payne had an inkling that this might be something to do with how these fish are removing lactic acid and dived into the data to find out.

Firstly, Iosilevskii and Payne wanted to check whether or not these fish really were zooming away after release. They examined the recorded swimming speeds of 29 large fish, belonging to 10 species of shark and one tuna species. Crucially, these species happen to be obligate swimmers, meaning they need to actively swim to pump fresh, oxygenated water across their gills. Imagine if you and I could only breathe by opening our mouths and running; you wouldn't be far off the situation experienced by these animals. The fish were caught by line and hook and were then held immobile in water for periods of up to 2 h while their measurements were recorded and a speed sensor was attached to a fin. For an obligate swimmer, this is exhausting. Iosilevskii and Payne were interested in what happened next and examined the swimming speed data recorded by the bio-loggers.

When released, most of the fish sped off at double their usual cruising speed, only settling down to normal swimming 6 h later. Most studies refer to this period as a 'stress response', and effectively ignore the data collected during this time. Iosilevskii and Payne instead thought the behaviour could be linked to the build up of lactic acid, which can only return to normal once high enough oxygen levels are available again.

At these swimming speeds, Iosilevskii and Payne estimated that these tired fish could get just enough oxygen from the water to dispose of the lactic acid but weren't at risk of overexerting themselves. They surmised that once the fish returned to their normal cruising speed, all excess lactic acid had been removed or stored elsewhere. So for you or me, this process of shifting lactic acid usually requires us to rest and catch our breath, but for a shark or tuna, it means just keep swimming.

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Iosilevskii, G., Kong, J. D., Meyer, C. G., Watanabe, Y. Y., Papastamatiou, Y. P., Royer, M. A., Nakamura, I., Sato, K., Doyle, T. K., Harman, L., Houghton, J. D. R., Barnett, A., Semmens, J. M., Maoiléidigh, N. Ó., Drumm, A., O'Neill, R., Coffey, D. M. and Payne, N. L. (2021). A general swimming response in exhausted obligate swimming fish. *R. Soc. Open Sci.* **9**, 211869. doi:10.1098/rsos.211869

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Hatching: a clever plan

It takes exactly 3 weeks to hatch chickens. This timing is incredibly consistent: once you place chicken eggs in a warm, plastic incubator, precisely 21 days later you have cute baby chicks. In the wild, no such plastic box exists to heat eggs, so instead mother hens 'brood' – they sit atop their eggs to warm them with body heat, and the eggs hatch exactly 21 days later. In other bird species, too, incubation periods are precise enough for mothers to do some family planning. Birds lay one egg at a time, usually over the course of a couple days. Sometimes, mothers don't heat the eggs until they're all laid; they incubate them in a batch, so all hatchlings emerge on the same day. But other birds, such as blackbirds (*Turdus merula*), sometimes incubate each egg as soon as it comes out, so incubation times are staggered and some siblings are older than others. However, older siblings steal all the food, which means the youngest hatchlings often starve and die. Still, many birds plan their families this way, incubating eggs at different times and leaving the youngest to suffer. Why would a mother willingly be so cruel?

Biologists once believed this was a strategy to save food in hard times: starve the youngest so the oldest can eat. But Juan José Soler and colleagues (Universidad de Grenada, Spain) weren't convinced – after all, mothers still feed the

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dying hatchling for over a week, wasting precious food. Instead, Soler's team questioned whether parents act differently with a hungrier mouth to feed – maybe a begging baby bird would motivate the father to gather more food?

To investigate, Soler's team watched blackbird nests outside throughout the spring breeding season. When eggs started to hatch, the researchers gingerly redistributed baby birds among the nests so that each bird family was structured the same: a father, a mother and four hatchlings. But in some families, Soler and colleagues substituted a hatchling that was a couple days younger than the rest. The lab tracked the food each parent brought back, tallying every insect fed to the chicks. It turns out all the families collected the same amount of food, but parents worked differently when there was a younger nestling. Mothers worked hardest when all the siblings were the same age, but they provided less food when there was a younger nestling constantly begging to be fed. Fathers took up the slack, diligently collecting food for the family.

Soler and team also tracked where the food went by labelling each nestling with fluorescent markers and tallying how much they ate and which parent fed them. Parents played favourites. Fathers fed the largest nestling but neglected the small adoptee. Mothers spread food more evenly, but even so, they underfed the runt of the litter. As Soler and colleagues underline, mothers fed the youngest hatchling only enough to prolong its life, but not enough to save it. And as long as there was a hungry and vocal hatchling crying out for food, fathers worked much harder to collect food for the family.

It is unlikely such a cruel egg-hatching strategy is without benefit. Soler's team points out blackbirds breed often, and females must avoid burnout if they're planning on a new family. So, while blackbirds condemn their youngest to death, it isn't in vain. These nestlings are sacrificed so their mothers might foster a new nest.

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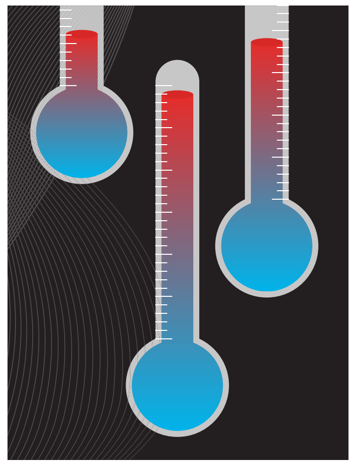
Heat waves harm fish brains

ECOPHYSIOLOGY



Climate change is causing heatwaves to become longer, more frequent and just plain hotter. For many of us, dealing with oppressive heat comes with several unpleasant challenges, from profuse sweating to feeling tired and sluggish. Humans, however, are not the only ones suffering through unprecedented heatwaves in a warming climate. In a ground-breaking study by Anna Andreassen and her team at the Norwegian University of Science and Technology, the researchers investigated what happens to the brains of larval zebrafish (*Danio rerio*) during extreme heatwaves, particularly as temperatures approach the upper limit of their heat tolerance. For these small fish, the consequences of unbearable heat are far worse than becoming a little sweaty.

Fish can only tolerate temperatures so high. At some point, they lose the ability to swim properly and assume the 'belly up' position (termed loss of equilibrium), an indicator of imminent death. For decades, biologists have wondered what happens in the body of fish at their upper temperature limit that prompts this behaviour. Andreassen and her team set out to solve this mystery by testing whether going belly up is caused by the brain not communicating properly with the rest of the body. This miscommunication is thought to occur because high temperatures stop nerve cells in the brain from functioning as they should. But first, the researchers needed a way to visualize the fish's brain activity at extremely high temperatures. Thanks to advances in genetic technology, they were able to study genetically modified zebrafish whose brains emit a fluorescent light when their neurons are active.

The researchers gradually increased the water temperature in the tank and observed the nerve cell activity of the genetically modified zebrafish using a microscope that could detect fluorescent light. At their upper temperature limit (approximately 40.9°C), the fish's brains showed very little fluorescence, indicating that the nerve cells were largely inactive. At this temperature, the larval fish were also no longer responsive to stimuli, such as bright lights flickering in front of their eyes. Interestingly, when the water temperature was raised by only 0.5°C above the upper temperature limit, something unexpected happened – the whole brain lit up as if the fish were having a seizure! This seizure-like activity was a sign that the brain had become completely depolarized, meaning that its nerve cells were firing on all cylinders, but not in a controlled manner. As this seizure-like event occurred at temperatures only slightly higher than the upper temperature limit, the team concluded that this is not what causes fish to lose equilibrium. Rather, they suggest that impaired neuron activity at the upper temperature limit is the mechanism underpinning this dangerous phenomenon.

The researchers decided to take their study one step further to determine why neurons stop working at the upper temperature limit. They had a hunch that high temperatures limit how much oxygen gets to the brain, which then impairs how its nerve cells function. Andreassen and her team repeated the heat ramping experiment, but this time at high, medium and low oxygen levels. They discovered that larvae exposed to high oxygen levels in the water did better at high temperatures than those in low oxygen; the fish had higher brain activity and recovered faster after being exposed to their upper temperature limit. Overall, these findings suggest that the amount of oxygen in the water plays an important role in controlling how the brain communicates with the body at extremely high temperatures. So, the next time you're sweating profusely in the midst of a summer heatwave, take a deep breath and be thankful that your brain function has remained intact.

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Neon goby fathers know best

The first life-altering step for a fish is leaving the safety of its nest and hatching into the big unknown. Researchers have long been fascinated with determining how embryos can discern when to hatch based on subtle cues from their environment. For the tiny neon goby (*Elacatinus colini*), the fathers decide for them, spitting the young from the seclusion of the nest when they feel the time is right. These small fish live in cylindrical sponges in the Belizean barrier reef, and the embryos are cared for by their fathers for up to a week before hatching. Armed with this knowledge, John Majoris from Boston University, USA, and a team of researchers from Humboldt University, Germany, and the University of Texas at Austin, USA, were interested in whether neon goby fathers can regulate the timing of their youngster's hatching and whether this translates to changes that would benefit the progeny once they hatched.

Majoris and his team went diving off the coast of central Belize to collect neon goby adults before shipping them to the lab at Boston University. To figure out whether the fathers regulated the timing of hatching, the team coaxed the breeding pairs to spawn. Ingeniously, the team was able to create transparent acrylic shelters that resembled the cylindrical sponges that the neon gobies naturally live in, allowing them to monitor the fathers' behavior before the embryos were due to hatch, and to video the hatching. When neon goby embryos were incubated with their fathers present, they hatched later, more in unison, and in a greater proportion than those incubated without their fathers present. This means that even though the embryos that were incubated with their fathers had the ability to hatch, they waited until the fathers gave their go-ahead to do so. The ability to hatch more in unison may also give neon goby larvae a leg up to life outside the nest by helping them deal with predators as they hatch.

The researchers also found that, after hatching, the embryos that developed with their fathers were bigger and more developed than those that did not, which can translate into hatchlings that are better suited to swimming and feeding. These fathers can directly influence their youngster's ability to survive because they can recognize optimal environmental conditions more easily than the embryos. This makes sense as the embryos usually develop in nooks and crannies of the reefs, making it difficult to discern the right time to leave the nest. This crucial decision by neon goby fathers can help their youngsters have an advantage after hatching, proving that fathers know best.

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