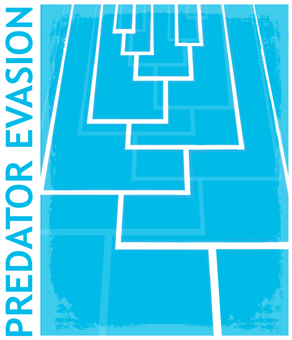
OUTSIDE JEB

Bright-eyed fish light up their predators



The relationship between predators and prey is often described as an arms race, with each side looking for new ways to better their opponent. Predators that rely on stealth look for new ways to blend into the background, while their prey adopt strategies to detect dangers lurking in the shadows. If you were a tasty little morsel, wouldn't it be great to be able to shine a light into these dark and dangerous places? Some fishes might be able to do just that. The eyes of triplefin *Tripterygion delaisi* have a mirror on the lower part of the iris, which they use to redirect sunlight into a beam that can be pointed sideways towards nearby objects. This so-called 'ocular spark' causes reflective eye-shine in the eyes of nearby animals, allowing them to be easily spotted just like the glowing eyes of a deer caught in the headlights. Triplefin use this trick to detect when their tiny plankton prey is nearby, and Matteo Santon at the University of Tübingen, Germany, wondered if triplefin could use the same technique to detect reflective eye-shine in their otherwise well-camouflaged predators.

The team's approach was to use tiny temporary baseball caps to prevent triplefins from using their ocular spark and then measure how close they would get to a predatory scorpionfish. Fish given clear caps could redirect sunlight from their eyes as usual, but fish that had their eyes shaded by opaque black caps could not.

Under laboratory conditions, triplefins fitted with opaque caps that shaded their ocular spark tended to approach their predators more closely than fish with clear caps. This exciting finding suggested that ocular sparks improved the ability of triplefins with transparent caps to avoid a nearby threat. However, the team performed these tests on captive fish under artificial conditions, so next, they strapped on SCUBA gear and sank aquariums to the sea floor to repeat the experiments under the most natural conditions possible. Just like in the lab, triplefins that were unable to use ocular sparks tended to approach predators more closely. Thus, lighting up the eyes of their predators seems to be an important triplefin safety mechanism.

Next, the team wanted to know exactly how much light can be redirected by an ocular spark and the farthest a predator could be before detection. Using a complicated mathematical model that included real-world measurements of how much sunlight is available, eye size and scorpionfish eye shininess, the team estimated that the ocular spark of triplefins could produce detectable eyeshine in scorpionfish that are about 6–8 cm away. This may not seem like a great distance but considering that triplefins are only 3–5 cm long, this amount of extra space could make the difference between life and death.

The arms race between triplefins and their scorpionfish predators marches on and it is hard to predict what the next steps will be. Perhaps scorpionfish eyes will become duller, or they will learn to keep them closed as prey approaches. But for now, triplefins seem to have gained the upper hand with their bright-eyed tactics.

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Cuttlefish keep their eyes on a 3D prize

Watching 3D films at the cinema might not be to everyone's taste, but it's hard to deny that the way the images appear to leap from the screen feels like technological movie magic. However, this visual trick relies more on stereopsis, a biological strategy by which some animals, including humans, use a pair of forward-facing eyes to measure how far away something is. Until a few years ago, it was thought that only vertebrates possessed this perceptive power and only very recently did scientists discover the use of stereoscopic vision in the first invertebrate species – predatory praying mantises. This revelation spurred Trevor Wardill and a team of visual ecologists from the University of Minnesota, USA, to investigate the possibility of stereopic vision in a much larger and more complex invertebrate carnivore – the cuttlefish.

Cuttlefish are unique amongst cephalopods, the class that they share with squids and octopuses, in that they have a substantial overlap in the range of vision between their left and right eyes. They are ambush predators, lurking close to their prey before rapidly grabbing them with tentacles and injecting them with deadly toxins. Since a mistargeted tentacle strike can result in their supper scarpering, cuttlefish rely heavily on precisely aiming and timing their strikes – a trait that Wardill felt made cuttlefish likely suspects for having stereopic vision.

To test his suspicions and confirm whether the common cuttlefish (*Sepia officinalis*) indeed use stereopsis for

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hunting, the team built miniature pairs of 3D glasses consisting of either red–blue or blue–green lenses, allowing them to present the cuttlefish with simulated images of prey set at specific distances. As cuttlefish lack a nose and ears for securing spectacles before their eyes, the team glued small pieces of Velcro to the sides of the animals so that they could attach the 3D spectacles with ease. Fortunately, a small number of the animals were unfazed by their new eyewear and carried on swimming and hunting as usual. Once accustomed to their new accessories, the team presented the cuttlefish with 3D movies of walking grass shrimp, a cuttlefish delicacy, on a TV monitor inside their experimental tank to lure them into striking.

The cuttlefish wearing the 3D glasses consistently positioned themselves correctly and extended their tentacles to just the right spot in order to land successful strikes at the shrimp movies. To test whether the cuttlefish could also judge distance without stereopsis, they were also shown images of shrimp that appeared in only one of the lenses of their 3D glasses, which removed the image's stereopic depth. This revealed that while the single-lensed cuttlefish were equally able to locate the shrimp, they took much longer to position themselves for the tentacle strike and would misjudge the distance to their fake food more often. While this result demonstrates the importance of stereopsis for speedy and accurate tentacle strikes, it doesn't seem be the only mechanism for depth perception in the cuttlefish's arsenal, as some of the single-lensed shrimp were still easily able to hunt successfully.

Despite their alien appearance, this curious case of convergent evolution goes to show that cuttlefish aren't quite so different to humans as once thought, but they do possess an extra stereoscopic skill that makes human eyes seem much less than picture perfect. For mammals, stereopsis and eye movement are closely linked, but surprisingly, Wardill's cuttlefish were moving their eyes independently like a chameleon for much of their hunting process; some were even still able to strike while their eyes were looking in different directions! When it comes to hunting for shrimp, seeing truly is believing – for cuttlefish, at least.

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Whales sneak up on their prey by hiding in plain sight

Rorqual whales, including the humpback whale (*Megaptera novaeangliae*), are large and fast. But their massive bulk isn't particularly manoeuvrable; imagine trying to catch a mosquito with a passenger jet. For these animals that hunt small and evasive fish, their poor manoeuvrability poses a problem. Instead, whales must use stealth. But when you're 30,000 kg, how do you sneak up on your prey?

David Cade from Stanford University, USA, studies the behaviour of humpback whales. Together with colleagues from St Louis University (USA) and Roma Tre University (Italy), Cade wanted to understand how whales trick their prey. To do this, they studied how individual anchovies (*Engraulis mordax*) behave when confronted with the threat of a looming whale. Of course, there are some major logistical challenges precluding laboratory-based studies of whales and anchovies, so, to get around the challenge, Cade used a beautifully simple simulation of a whale looming over the fish. He mounted a TV screen showing a dilating black circle behind the anchovy's tank. This circle represented not only the shadowy looming shape of a whale accelerating towards the fish, but also the opening of its jaws. As the circle reached a particular 'looming threshold', the fish thrashed their bodies. En masse, this has the effect of dispersing the school, and reducing the chance of a mouthful of fish for the whale. The team then varied the patterns and speed of the circle dilation, to see which of the whales' hunting strategies might be the most successful.

Analysing the anchovies' reactions, the team found that the tiny fish were most threatened by the prospect of a whale approaching with opening jaws. However, the fish were less threatened when the simulated whale approached with its jaws closed, even when the whale approached at faster speeds. In short, the whales' large size, combined with their long bodies, tricked the fish into downplaying the threat. Having figured out which aspects of a whale approach sent the anchovies fleeing, Cade and colleagues then wondered whether humpback whales in the wild wait until the final split-second before opening their mouths. Examining video footage from a previous study of anchovy-hunting humpbacks off the coast of Southern California, the team found that the anchovies did indeed disperse just as the whales opened their mouths, but by then it was too late.

However, it wasn't clear how humpback whales maximise their catch. Cade used a predictive model of how individual fish in a school would behave during different whale approach strategies. They found that the whales are able to make the largest catches by approaching at high speeds and when using their fins to confuse the fish. But with this strategy, timing is everything; if the moment when the whale begins to open its jaws is delayed even by an instant, the whole school will be lost. In addition, the team found that the whales depend on team work, by feeding alongside common dolphins and California sealions. The other mammals help by herding the fish into densely packed bite-sized schools, ready for the whales to plunder.

The humpback whales' ability to sneak up on fish is part of an evolutionary arms race and, since whales are a relatively recent arrival, fish such as anchovies have not yet figured out how to mount an effective escape. Whilst this isn't great news for the fish in question, hiding in plain sight from their dinner might be one reason that humpback whale populations have been able to stage their spectacular recovery from near collapse. Their large body size, once a tempting target for whalers, is paradoxically now their greatest asset.

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Too hot or just right during embryonic development in lizards?

PHENOTYPIC PLASTICITY

Variations in environmental conditions during embryonic development can have a profound influence on the trajectory of on organism's life. For example, if a mother breathes in polluted air, then the toxins in the air can alter gene expression in the developing baby and change a phenotype – an observable trait associated with a gene. Thus, genes can produce vastly different traits if they are affected by environmental triggers. Biologists call this phenomenon 'phenotypic plasticity' and it has particular ecological relevance for many ectothermic (cold-blooded) animals, such as lizards. Unlike humans, whose babies are well protected from environmental fluctuations inside their mothers, lizards lay eggs that are very susceptible to outside changes in climate.

Climate change is a man-made effect that has intensified extreme-weather events globally, including making temperatures soar. Given the potential risk rapidly increasing temperatures will have on the survival of heat-sensitive animals, Alex Gunderson and colleagues from Tulane University, USA, and Auburn University, USA, wanted to know if exposing embryonic lizards to high temperatures would make them more susceptible to hot temperatures or prime their physiology to become heat-tolerant.

The team selected a common lizard, the Cuban brown anole (*Anolis sagrei*), and subjected their eggs to three temperatures that represent the natural range that anoles experience in nature: a cool (27°C), warm (33°C) or hot (40°C) temperature. The team observed an immediate effect of temperature on the eggs; only 40–57% of eggs exposed to the warm and hot temperatures survived, in contrast to the cool eggs, which had a 90% survival rate. Considering that climate change is expected to push temperatures in some regions to their upper limits, this finding is concerning, as it shows that an enormous proportion of eggs that are persistently exposed to higher natural temperatures might succumb to heat-stress.

Of the eggs that hatched, the team raised the lizard youngsters at 25°C (room temperature) to adulthood, before testing their heat tolerance. Then, knowing that lizards eventually hit a critical temperature at which their muscles fail, the scientists slowly warmed the lizards from 36°C and flipped them on to their backs. Every time a lizard successfully turned over, indicating that their muscles were still functioning, the team raised the lizard's body temperature by 1°C and tested its righting ability again. If the lizards had benefited from their warm incubation, then they might be able to continue righting themselves at temperatures where the cooler lizards failed. However, the results were both surprising and alarming. Surprising, because all the lizards, regardless of whether they were raised in cool, warm or hot conditions, lost the ability to right themselves when temperatures were higher than 39°C. In other words, the temperature that the lizards experienced while they were embryos had no effect on their heat-tolerance as adults, which is alarming, because of the implications for reptile populations worldwide.

Given that scientists expect climate change to elevate global temperatures in the years to come, reptiles might not benefit from phenotypic plasticity as embryos if exposed to extreme temperatures. Considering that a number of reptilian species live and reproduce in areas with very high daily temperatures, an increase of only a few degrees could have severe ecological consequences for their populations.

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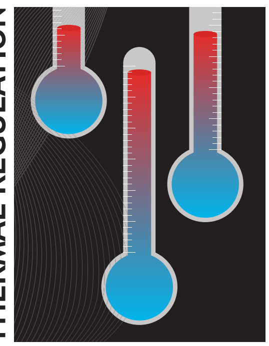
Cooling down hot wings

THERMAL REGULATION



When butterflies display their spectacular wings on sunny days they are not just showing off their good looks. Spreading out in the sun allows their wings to heat up after they have been cooled by circulating air during flight. However, butterflies cannot fly if their wings get too warm, so they have to be able to monitor the temperature of their wings and stop them from overheating, either by closing their wings, tilting their bodies to absorb less sunlight or walking to a less sunny spot. To understand how the animals decide when to stop basking, a team of researchers at Columbia and Harvard Universities, USA, developed a camera fine-tuned to see the heat spectrum produced by the sun on thin material like wings. They found that the colourful displays that we see on butterfly wings are part of a story, which only becomes evident when you can see temperature as well.

In order to compare reactions to heat on different wing shapes, the team looked at more than 50 butterfly species. They heated the wing at different points with a sun-mimicking laser and found that all of the butterflies stopped basking as the temperature rose, regardless of their wing shape or the location of the heat spot. This finding suggests that heat-sensitive structures that detect temperature are distributed evenly across the surface of the wing. The camera also showed that the undersides were cooler than the upper sides, which may explain why butterflies fold up their wings when they are overheating.

In addition, the camera revealed that temperature can vary enormously across a single wing, by as much as 15°C. Under the camera, it was clear that the veins and sensory structures remain cooler than the membrane in between. The team predicted that this difference in temperature is due to the structure of the scales covering areas of the wing that are important for sensing the environment. To test this theory, they gently removed scales and imaged the wings again with their temperature-sensitive camera. Without scales, most of the previously cool parts of the wing were the same warm temperature as the wing membrane, while other cool parts of the wing remained cool due to the thinness of the underlying membrane.

The structure of the wings, along with actively avoiding the sun, allows butterflies to catch our eyes while staying cool enough to fly.

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