

OUTSIDE JEB

The electric eel's buzz explained



In the swamps and creeks of the Amazon and Orinoco river basins, a legendary predator lurks in the muddy depths: the electric eel. Said to be capable of paralysing animals the size of a horse with its electrical discharges, it has been the subject of countless experiments over hundreds of years: it inspired the design of the first battery by Volta and has been used to study the workings of the interface between nerve cells and muscles. Astonishingly, we still have little idea of how the eel actually uses its electric organ to capture prey. What we do know is that the electric eel is capable of producing three types of electrical discharges: a slow, low-intensity mode while exploring its environment, pairs or triplets of high-intensity pulses of unknown use, and an all-out, high-intensity mode, consisting of dozens of pulses over a few seconds, to capture prey or defend against attacks. A major hurdle to understanding electric eel predatory behaviour is that much of it simply occurs too quickly for the human eye to detect.

However, in one big sweep, Kenneth Catania of Vanderbilt University has filled in many of the gaps in our understanding in a highly insightful paper published recently in *Science*. He decided to overcome the limitations of the human eye by using a high-speed camera to track the behaviour of electric eels as they try to capture their prey (in this case small fish). Catania noticed that very quickly after the eel's first discharge of the high-intensity burst, prey were

paralysed. How does this fast incapacitation occur? In order to address this question, Catania placed an experimentally incapacitated prey fish in the aquarium, separated from the eel by an agar wall, which, while acting as a physical barrier, still conducts electric fields.

As expected, when the eel generated the volleys of high-voltage pulses that it normally uses to capture prey, the prey fish tensed up. However, when Catania injected a drug into the prey that inactivates the connections between the nervous system and the musculature, this response no longer occurred. This shows that the eel incapacitates its prey by inducing electrical activity in the nervous system, which in turn makes the muscles contract uncontrollably.

When Catania looked more carefully at the eel's predatory behaviour, he saw that, in complex environments, pairs or triplets of discharges often precede high-voltage bursts. Moreover, the doublets or triplets always produce movement in the prey. Could this mode serve to detect prey under difficult conditions by forcing them to reveal themselves? In order to test this, Catania put incapacitated prey fish in a plastic bag in the aquarium, which electrically isolates them from the eel. Then, Catania connected the prey fish with electrodes, which allowed him to induce movement in the prey fish.

Catania noticed that, when an eel fired a doublet or triplet, the eel would only attack the prey when Catania induced movement in the fish. This shows that the eel uses the doublet or triplet to confirm that it is dealing with live prey, rather than one of the many inanimate objects in the complex environment that the murky bottom of a swamp provides.

This study elucidates how the electric eel uses its electric organ to draw out, detect and incapacitate its prey. Furthermore, it comprehensively shows that we should be grateful we're not small fish in the Amazonian basin.

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Chilled-out iguanas have bird-like lungs



For decades, birds enjoyed the reputation of being the only known animal group to have unidirectional airflow in their lungs. This unique lung design had long been assumed to be an adaptation to the high oxygen demands of intense activity, and is thought to have enabled the evolution of flight. A unidirectional flow of air through the lungs means there is a constant stream of fresh oxygen being delivered to the bloodstream, whether the bird is breathing in or out – quite unlike that of the mammalian lung. A new study, published in the *Proceedings of the National Academy of Sciences*, has thrown doubt on the long-held belief that unidirectional airflow in lungs evolved for intense activity and stamina, by finding bird-like lungs in green iguanas – a species not renowned for its flight capabilities or aerobic fitness!

Colleen Farmer and colleagues, based at the University of Utah, USA, designed a series of novel methods for investigating airflow through the lungs of the iguanas. First, the team watched, via an endoscope, as the lizards inhaled harmless particle-laden theatrical smoke, allowing visualisation of the airflow through the lungs. To the team's amazement, the smoke particles only

moved in one direction, regardless of whether the iguanas were breathing in or out. Following this surprise, the team then pumped water full of pollen grains through surgically removed lungs, to further clarify how the air flowed through these structures. Coupled with computer simulation models, Farmer and colleagues were able to confirm that the iguana's lungs exhibited unidirectional airflow and the lung design matched that of birds! Given the dramatic difference in natural history between the two groups, it begs the question, why would iguanas have evolved a lung morphology that is typically associated with intense aerobic activity? Moreover, Farmer adds, 'It even suggests that unidirectional flow is not necessarily important for expanded aerobic capacity'.

These findings imply unidirectional airflow evolved not just for flight but also for some other vital life-history aspect. The authors propose that unidirectional airflow is linked to the ability of reptiles to hold their breath for long durations. Green iguanas are known to swim and dive to avoid predators, and a unidirectional lung design could potentially extend the period the lizards can stay submerged underwater. The iguana's lung design implies that unidirectional airflow evolved both before flight and the first birds and it was more than likely present in a common ancestor over 250,000 million years ago, before the Diapsida group split into the Lepidosauromorpha (tuatara, lizards, snakes) and Archosauromorpha (crocodilians, birds) that we see today. Asked whether this lung design could possibly be an example of convergent evolution, Farmer explains, 'It would be a striking case of convergence if it turns out to be the case'.

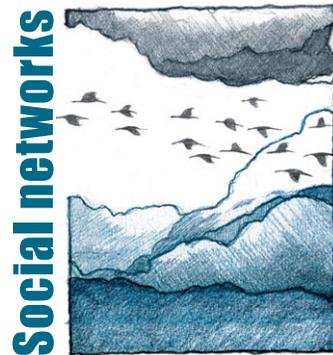
So it appears that birds may have lost their exclusivity with respect to a unidirectional lung design and will now have to share this accolade with certain reptile species. The direction of airflow through the lungs of reptiles has largely been assumed, rather than definitively measured. Consequently, it is likely that further investigations will result in bird-like lung designs being identified in more reptile species, questioning further the exact function of unidirectional airflow.

10.1242/jeb.112102

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Stressed-out birds make more friends



We may not think of childhood as a particularly stressful time in our lives, but growing up is scary. There are rules, actions and consequences that all young things must learn fast in order to survive. These early experiences can play a huge role in shaping individual behaviour and fitness in later life. So how should juvenile animals deal with stress during their development? Researchers at St Andrews and Oxford University, UK, say it's easy: just make friends.

Neeltje Boogert and her colleagues were interested in the developmental factors that drive individuals to become more or less social later in life. They suspected that stress, which young wild animals typically experience during periods of food shortage or sibling rivalry, plays a role in how individuals grow and develop into social adults. They tested their theory using a captive population of zebra finches (*Taeniopygia guttata*) in which they experimentally increased exposure to the avian glucocorticoid stress hormone, corticosterone. When the experimental chicks were 12 days old, half were fed a diet of peanut oil and half were fed peanut oil laced with corticosterone over the next 16 days. Boogert and her team then fitted the

chicks and their parents with passive integrated transponder (PIT) tags to record their movement and interactions around experimental feeders in two free-flying aviaries over a 5 week period. The individual barcodes associated with the PIT tags recorded data on who was foraging with whom, which birds stayed close to their parents and which birds had more foraging partners. In essence, Boogert could see whether the stress hormone treatment predicted which individuals developed into the 'social butterflies' of the bird flock.

The group initially expected the corticosterone-treated chicks to be less social than their untreated siblings, based on some earlier research in great tits (*Parus major*). However, the zebra finches appeared to take stress in their stride, and responded to early-life corticosterone exposure by becoming more independent from their parents and spending more time with a wider variety of individuals compared with controls. Social network analysis also showed that stress-treated birds occupy more central positions in the network: in other words, they are more gregarious than their less social untreated siblings. The downside of this social flair is the strength of the friendships. The stress-treated birds formed weaker associations than the untreated birds as they tended to form fewer tight-knit associations.

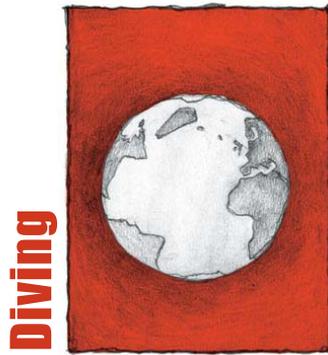
Does having an outgoing social life help or harm birds in the long run? More research is needed to answer this question. If stress encourages independence in young birds, this may facilitate their dispersal away from poor habitats in the wild. However, fewer, but more stable friends may be better than many flaky ones when the going gets tough. In any case, these results make me reflect back on the times I was bullied as a kid...perhaps I have more friends today because of it!

10.1242/jeb.112086

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Fat seals forage most efficiently



Northern elephant seals are truly impressive divers. During months-long migrations, they spend most of their time underwater, diving hundreds of meters down into the sea. What's even more impressive is that these animals are breath-hold divers. This means that they must empty their lungs of air, and dive, dive, dive...until they reach their feeding grounds, where they forage for up to half an hour before making their way back up to the surface for more air. Because this type of diving is energetically expensive, seals must balance the costs of diving with the benefits of remaining at the bottom long enough to eat sufficient food to make it worth the trip. And the amount of fat a seal has determines how easily it moves up and down through the water – lean (negatively buoyant) seals fall fast, but must work harder to swim back up to the surface. While mathematical models

have suggested that being neutrally buoyant, as the seals are when they are fat from months of feeding, may reduce total overall locomotor costs and allow the seals to spend more time at the bottom foraging, testing this prediction in nature on deep-diving, long-term migrating marine mammals has proved challenging. But that didn't stop Taiki Adachi, at The Graduate University for Advanced Studies in Tachikawa, Tokyo, Japan, and his team of international collaborators from seeking the answer to the question, are fatter seals more efficient foragers?

Adachi and his team developed an instrument (a stroke logger) that allowed them to record acceleration and pitch angles at high sampling rates and attached these, along with data loggers and transmitters, to female northern elephant seals (*Mirounga angustirostris*) before the seals journeyed on two foraging migrations – a 2 month post-breeding season migration and a 7 month post-molting season migration. They also recorded the seals' body masses and external physical measurements. Using stroke loggers, the authors estimated the body composition of the seals based on the rate of vertical passive descent or ascent (drift rate) of the seals, as drift rate is strongly correlated to body density.

The researchers found that short post-breeding migration did not result in a shift from negative to neutral buoyancy – that

is, the seals did not amass enough fat to change how quickly they fell through the water column, or how hard they had to work to get back up through it. However, by the end of recording during the long post-molting migration, the seals were fatter, more buoyant and had fewer swimming strokes per trip than when they were leaner. The big reward for the increase in fat was that it allowed the seals to spend more time at the bottom of the sea foraging. The authors suggest that a reduction in oxygen consumption during the dive may allow the seals more energy to use during their time foraging.

Many marine mammals have similar diving and foraging strategies to these seals, and the authors propose that there could be potential locomotor costs for other marine mammals when straying from the optimal body composition. Although future studies including measurements of metabolic rate would provide a more complete picture of the energetic costs of diving and foraging in marine mammals, one thing seems clear – for these seals, it pays to be fat.

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