

Inside JEB is a twice monthly feature, which highlights the key developments in the *Journal of Experimental Biology*. Written by science journalists, the short reports give the inside view of the science in JEB.

Inside JEB

CORNERING COCKATOOS



Picture by Ty Hedrick

As a bird takes to the skies, it might have to manoeuvre around a slalom course, avoiding obstacles, other birds and escaping from predators. However how they do it isn't that well known, partly because many birds such as pigeons struggle to learn how to fly around corners in the lab, and refuse to fly in wind tunnels. Fortunately, as Ty Hedrick explains, members of the parrot family are quick learners so he travelled to Australia to study the brightly coloured rose-breasted cockatoo, which can master flapping around a corner in the lab in only 30 minutes (p. 1897). Together with his colleague Andrew Biewener, Hedrick says that the first question they wanted to answer was, 'how do they do it?'.

First, the team trained the birds to fly down a 7 m long 'L' shaped tunnel, with a tight 90° corner 3 m down. Interested to know how the flight muscles were active as they flew around corners, they anaesthetised the birds before inserting small EMG wires into the two large chest muscles, the pectoralis and the supracoracoideus, which are the powerful 'flight engine'. They also inserted wires into some of the many small wing muscles, before feeding all the EMG wires into a cable attached to the birds' backs which they carried behind them as they flew along. The team also placed markers on key joints so that they could monitor the movements of the cockatoos' wings during flight using high speed cameras.

When they looked at the birds' movements in more detail they found that they turned around the tight bend by rolling, much like

an aeroplane does when it turns. 'Even for this type of turn, the differences between the wings were very subtle,' Hedrick explains. Teasing apart the wing movements in more detail, they found that the wing on the outside of the turn worked harder at the beginning of the turn while the inside wing flapped harder at the end of the turn to get the bird straight again. This was caused by the birds slightly altering their wing movements which changed the forces that each wing generated and therefore changed their orientation. At the beginning of the turn the outside wing swept through a larger arc and rotated at the shoulder to meet the air at a steeper angle than the inside wing, which was held at a shallower, flatter angle. On the second half of the turn, the wings switched roles with the inside wing moving through a larger arc and meeting the air at a steeper angle, generating more force than the outside wing to get the bird straight again.

Looking at the muscle activity in more detail, Hedrick says that 'there was not a turning muscle'. Instead, there were subtle changes in the activity of all the muscles to help the bird get around the corner. So rather than changing the activity of the flight engine in a big way, cockatoos use small changes in their wings to turn, much like an aeroplane uses wing flaps and a rudder.

Having described how the wings and muscles were working during turning, Hedrick and Biewener teamed up with Jim Usherwood to work out how they were doing it (p. 1912). Because they knew the mass of each bird and their exact trajectory and speed, they could calculate the forces the cockatoos generated as they turned. They wanted to know how the birds used changes in the inertia of the wings, and changes in the aerodynamic forces to turn. To do this they used a mathematical model which estimates forces acting on the wing and takes into account the fact that the wing is not uniform in size, shape or movement. 'We use models to test how we think wings work,' says Hedrick. So, if their model predicted similar forces to the ones they had calculated, then they would know that the model was doing its job well.

They found that the inertia of the wings and changing the balance of the forces were equally important over shorter timescales, for example during part of the upstroke or downstroke, while aerodynamic adjustments were more important over a whole wing beat. However, just like with the muscles, the team found that there were many small adjustments that were contributing to the overall effect. The model came quite close to

estimating the forces that they had calculated, such as lift and torque.

Hedrick explains that the results show that turning is not that simple, but that they were pleasantly surprised that the model worked as well as it did to predict the forces acting on the wing. 'This show that our understanding of aerodynamic factors is better than expected,' he says. 'It's good to know that we are on the right track!'

10.1242/jeb.007401

Hedrick, T. L. and Biewener, A. A. (2007). Low speed maneuvering flight of the rose-breasted cockatoo (*Eolophus roseicapillus*). I. Kinematic and neuromuscular control of turning. *J. Exp. Biol.* **210**, 1897-1911.

Hedrick, T. L., Usherwood, J. R. and Biewener, A. A. (2007). Low speed maneuvering flight of

LUNGFISHES' BALANCING ACT

Our bodies are constantly working to keep everything in balance; when we exercise, not only do we breathe harder to get more oxygen to our muscles, but also to get rid of the painful lactic acid 'burn'. All air breathing land dwellers deal with acid – an excess of protons – by reacting protons with bicarbonate ions to create water and CO₂, which is breathed out. To deal with too much base, breathing slows down, keeping CO₂ and therefore protons in the body. Water breathing fish take a different approach, relying on metabolic processes at their gills and kidneys to restore a normal blood pH. But how will animals that can breathe in both air and water deal with pH changes? 'Lungfish are poised between air



Picture by Antoine Morin

breathing and water breathing, and are a beautiful model to study this,' says Katie Gilmour of the University of Ottawa, who investigated with her colleagues if lungfish cope with pH changes like air breathers or water breathers (p. 1944).

Lungfish bridge the divide between land and water, dependent on their watery environment for food but dying if they can't breathe air with their lungs. They also have gills, which they use to water breathe and get rid of some CO₂. Once the team's fish had arrived in the lab from their African home, they trained them to sit in water-filled tube respirometers and pop their heads above the water's surface when they needed a gulp of air.

To find out how the fish would deal with an excess of acid or base, they delicately operated on them to insert a cannula into the dorsal aorta, so that they could change blood pH by injecting acid or base into the blood stream. To find out how the fish dealt with an acid injection, they counted the number of air and water breaths, finding

that they took twice as many of both and breathed out more CO₂, much like a land dweller. To see if the gills or kidneys were also getting rid of excess acid, the team measured acid excretion into the water in the respirometer. They didn't see a rise in excretion from normal levels, suggesting that lungfish don't rely on their gills and kidneys much to get rid of excess protons.

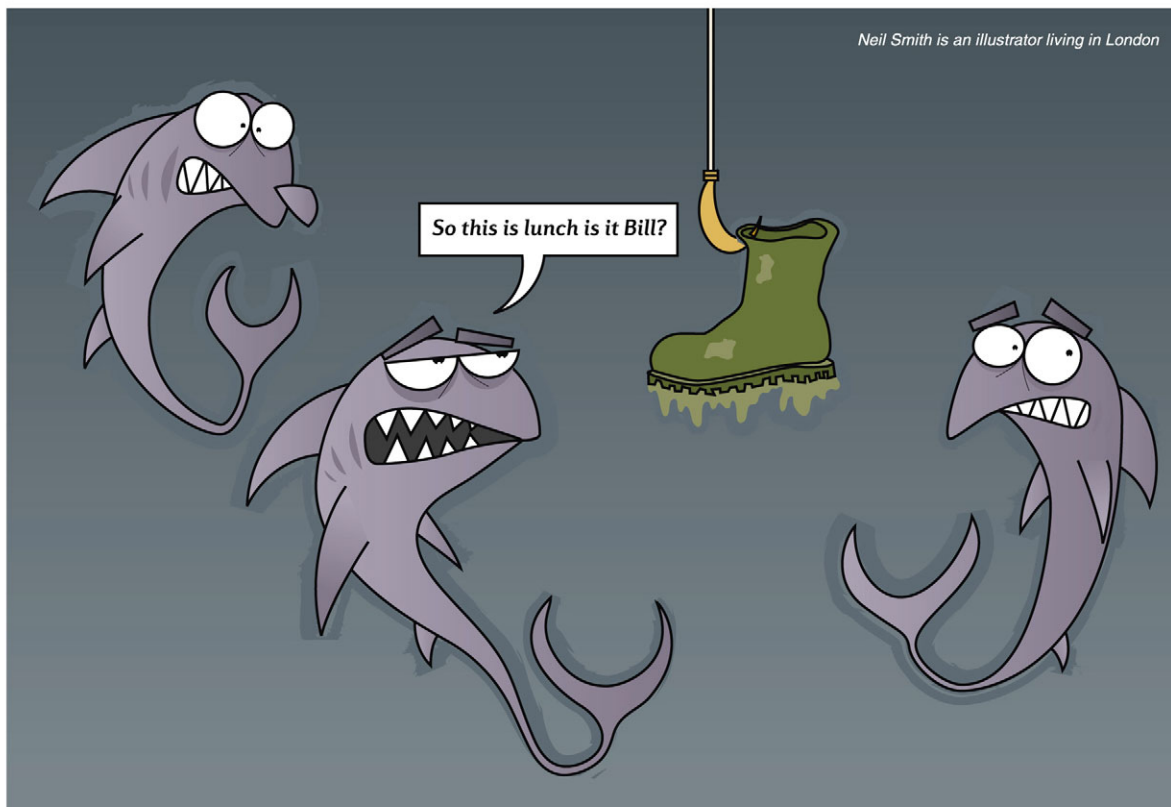
Injecting base and raising blood pH caused the fish to halve their water breathing rate; they also breathed out much less CO₂ into the water. Their air breathing was unaffected, however, probably because they wouldn't get enough oxygen otherwise. The team measured that the fish were excreting much higher levels of base into the water, so to separate out how much the gills and kidneys were each contributing, they collected the fishes' urine via a catheter. They found that the kidneys excreted around 20% of the total base into the urine, and the gills around 80% into the water, much like fish, showing that the lungfish rely more on the water breathers' strategy to get rid of excess base and rebalance pH.

'The lungfish have the best of both worlds,' says Gilmour. Like land dwellers, they rely more on air breathing to redress a more acidic blood pH, but their gills and kidneys deal with an excess of base to return blood pH back to normal, just like water breathing fish.

10.1242/jeb.007419

Gilmour, K. M., Euverman, R. M., Esbaugh, A. J., Kenney, L., Chew, S. F., Ip, Y. K. and Perry, S. F. (2007). Mechanisms of acid-base regulation in the African lungfish *Protopterus annectens*. *J. Exp. Biol.* **210**, 1944-1959.

HOW SHARKS SENSE SMELLS



Neil Smith is an illustrator living in London

The smooth dogfish, *Mustelus canis*, is a small shark that feasts on lobster, squid, and other small shellfish, finding its food by tracking odour plumes. It doesn't just follow its nose, but also relies on the movement of the water and vibrations, picked up by its lateral line system, to find its meal. Jayne Gardiner and Jelle Atema wanted to know how the dogfish used their different senses – smell, mechanoreception by the lateral line and vision – to track odour plumes in a large flow tank (p. 1925).

The sharks had two odour plumes to choose from: seawater or yummy squid juice. Each plume was squeezed out of a small nozzle to create a relatively smooth 'oozing' odour source, which became turbulent as it flowed

over a brick 15 cm downstream of the nozzle. When the lights were on, and all their senses were intact, the sharks preferred the turbulent part of the odour plume, indicating their choice by biting or nudging the brick. When the team knocked out the lateral line using streptomycin, the sharks had to search for longer, but couldn't distinguish between turbulent and oozing odour, suggesting that they couldn't tell the difference between smooth and turbulent flow without their lateral lines.

When the team plunged the sharks into darkness, the intact sharks had no problems choosing the turbulent odour, however those whose lateral lines weren't working rarely found the odour plumes. The few

sharks that did find them couldn't tell the seawater or squid odours apart. This shows that sharks need both their lateral line and sense of smell to track odours. If their lateral line is not working, vision can help them to find the source of the smell, but if the lights go out, the fish have big problems, and might go hungry.

10.1242/jeb.007427

Gardiner, J. M. and Atema, J. (2007). Sharks need the lateral line to locate odor sources: rheotaxis and eddy chemotaxis. *J. Exp. Biol.* **210**, 1925-1934.

Laura Blackburn
laura@biologists.com
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