

OUTSIDE JEB

Stunning suppers with an electric attack



In the murky waters of the Amazon River, electric eels (*Electrophorus electricus*) bombard their prey with quick-fire bursts of electricity. Just like a TASER, a rapid volley of electrical impulses causes repeated muscle contractions and immobilizes prey. Eels can then swallow their unlucky victims whole. Although this electrical weaponry is around two and a half times more powerful than the discharge from a UK electrical socket, this might not be enough to successfully stun many prey available in the Amazon. Kenneth Catania suspected that a unique behaviour might help eels intensify their attack to expand their menu.

Central to an eel's electrifying attack is an organ containing thousands of electrocytes, which runs down most of an eel's body. Individually, each electrocyte can only release a small charge, but when lined up in series like cells in a battery, electrocytes can discharge 600 V. In theory, to 'amp' up their attack, eels could increase the voltage that these electrocytes produce. However, it is possible that they may have evolved a more elegant alternative. In a typical attack, captured prey are locked between an eel's jaws, where they are exposed to electric impulses originating from behind the eel's head. However, Catania consistently observed eels looping their bodies around prey. This curling behaviour brings the negative pole of an eel's electrogenic organ (the tail) closer towards its positive pole (the head). Catania

reasoned that prey sandwiched between the two poles of an eel's body would experience a more intense electrical field.

To test this idea, Catania inserted electrodes into dead pithead fish with viable muscles and presented these to eels. He found that when eels looped around fish, the voltage that the dead fish experienced more than doubled. By simply repositioning their bodies, these eels can exploit the physics of electrical fields to unlock their full electrogenic potential.

To see what effect this had on prey, Catania exposed pithead fish and crayfish tails to the high-voltage impulses that they would experience if held between the poles of an eel's body. He found that an amplified electric attack over-activates the victim's muscles, leading to a rapid drop in contractile force. The result is that by looping around their prey, eels quickly cause involuntary muscle fatigue.

Given that a standard monopole attack is already incredibly powerful, why do eels intensify their field? The answer probably lies in eel feeding behaviour. Eels must release their stunned victim to reposition it before swallowing it head first. This brief respite is the last opportunity for prey to recover and dart away. By causing fatigue in the muscle fibres central to anti-predation escape manoeuvres, the eels are able to incapacitate their prey so that they are less able to exploit this last chance of escape. This looping behaviour therefore helps eels subdue their victims, and might allow them to better tackle the well-armoured and electric-field-generating prey that may be available to them in the Amazon River.

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Catania, K. C. (2015). Electric eels concentrate their electric field to induce involuntary fatigue in struggling prey. *Curr. Biol.* **25**, R1070-R1072.

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Tendon elasticity helps bats flap



Tendons, whose primary function is to anchor muscle to bone, can also serve as essential locomotion tools. Some tendons act as springs to aid terrestrial animals that bounce and run along the hard ground. These tendons increase force and power and help to recover energy that would otherwise be lost during movement. Even some animals that move within a fluid system, such as pigeons, have been shown to benefit from elastic tendons during flight. But not all tendons are elastic. Many animals have rigid tendons that act more like cords. These tendons do not confer any elastic benefits to the muscle. This is especially true for small animals, whose tendons are relatively thick for their size.

Bat wings have rather long bones with suitably long tendons. Nicolai Konow and his collaborators at Brown University, USA, wanted to understand what these long tendons were doing during bat flight – were they simple rigid cords acting to leverage the wing (flap, flap), or were they springy enough to confer some sort of mechanical advantage to the bat during flight?

To answer this question, the team at Brown filmed four Seba's short-tailed bats (*Carollia perspicillata*) with a high-speed X-ray system to track the movement of the triceps muscle, its tendon, and the elbow joint during ascending flight as the bats flew through a tube. They also implanted radio-opaque spheres in the bone and at the junction of each bat's triceps muscle and tendon. This allowed them to track the length of the muscle as the elbow joint flexed and extended during each wing beat.

They found that the changes in joint angle and muscle length during flexion and extension were not synchronized, as they would be if the tendon was stiff. They also found that the triceps muscle contracted almost 25% less than would be expected with a stiff system. So not only were the bats' wing tendons elastic, but they were also reducing the amount of work the muscle was doing – the tendon was doing it instead.

Konow and colleagues state that because wing movement is cyclic, the elasticity of the triceps tendon allows for a recycling of mechanical energy during bat flight. The energy stored between the downstroke and the upstroke is then released during the late stage of the upstroke. The authors say that this timing is key, as the late stage of the upstroke is when the wing is positioned for force production during the next downstroke. The next step in understanding the importance of tendon elasticity in the bat wing, they say, is to estimate the actual amount of energy stored and released during this cycle.

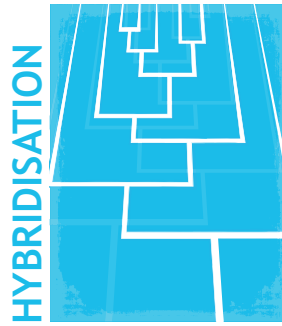
Previous work with pigeons has shown similar elasticity in the tendons powering flight, but not in the case of other tendons in the same birds and not in tendons of other small animals – even though these tendons are crucial for locomotion. So which tendons aid locomotion by virtue of their elasticity is still being explored in different animals and types of movement. Although some mysteries of tendon elasticity remain unresolved, it now appears clear that elasticity helps power bat flaps.

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Hybrid fish sucks at feeding



Any farmer will tell you that to get the strength of a donkey with the temperament of a horse, mate them to get a mule. This genetic swapping between species has been orchestrated by humans for centuries to create hybrids with desirable traits. Nature also sometimes confuses the reproductive rules. Wild populations of hybrids often persist alongside their parent species and many even look like a cross between the two. Unfortunately, this cut-and-paste approach to speciation has some downsides: just ask the mule, which is, of course, sterile. Although we know a lot about the reproductive disadvantages of inter-species relationships, it is unclear whether hybrids face everyday challenges as well. This knowledge gap piqued the interest of researchers from the University of California Davis, Texas A&M University and Towson University in the USA, who set out to measure exactly how much one hybrid sucks.

Matthew McGee and colleagues focused on a common cross between the bluegill sunfish, *Leopomis macrochirus*, and the green sunfish, *L. cyanellus*. Each of these parent species has a body and mouth specially adapted for feeding on certain food types. Bluegills are deep bodied with small, powerful mouths used to suck invertebrates off rocks. Conversely, green sunfish are slender and prefer to gulp fast-moving prey with their large mouths. The

hybrid has an intermediate body and mouth shape, but just how this translates into feeding performance is unknown. The researchers used high-speed cameras to film live bluegills, green sunfish and crosses while feeding on mobile prey. The videos were then used to measure the timing and movement of the fish's mouth during an attack. From this information, they were able to estimate each fish's capacity to generate suction pressure. This suction index was then used to simulate an individual's feeding performance on either attached or free-swimming model targets.

Not surprisingly, the overall mouth kinematics and speed of the feeding hybrids fell right in between that of their parents. And performance simulations suggest that hybrids are not as good at bluegills at dislodging attached prey, nor as able as green sunfish to suck mobile food out of the water. In fact, with each type of simulated prey, the hybrids performed about as well as their worst performing parent. In other words, intermediate morphology does not equal intermediate performance.

The fact that hybrids inherit a master-of-none morphology that translates into poor performance is surprising given what we assume about body form and function. Interestingly, these results suggest that the relationship between performance and morphology is non-linear, meaning that it can be hard to infer the actual function of a body part from its shape alone. The mule might be a jack-of-all-trades, but it looks like the performance of most hybrids is not even stuck somewhere in the middle. It just sucks.

10.1242/jeb.129890

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Anaemic starlings have fewer chicks (sometimes)



To boost aerobic performance, fraudulent athletes engage in blood doping to increase the haemoglobin levels in their blood. Surprisingly, however, during reproduction – a period of huge metabolic investment into the next generation – birds often exhibit a reduction in the haemoglobin concentration in their blood. This is due, at least in part, to increased levels of oestrogen that suppress the formation of new red blood cells. Reproductive output is at the crux of Darwinian fitness, so the possibility that anaemia compromises breeding success has clear evolutionary relevance. However, evaluating the importance of oxygen transport by haemoglobin in supporting reproductive exertions represents no small challenge.

Undaunted, a team from Simon Fraser University, Canada, including Raime Fronstin, Julian Christians and Tony Williams, recently investigated the link between haemoglobin and reproductive

success in wild starlings. Over 3 years, they monitored approximately 150 nest boxes at a local dairy farm and accurately recorded when each bird laid eggs, the number of eggs in a clutch and the size of the chicks. The authors also collected blood samples from the birds during the course of their observations. Then, through a series of elegant experiments, they related the measurements of the birds' reproductive output to their haematology.

Fronstin and colleagues first investigated the natural variation in haematocrit (the percentage of blood volume occupied by red blood cells) in their starling population. From each nesting bird, they took a baseline blood sample, which revealed that females with haemoglobin-packed blood laid their eggs considerably earlier and raised more fledglings than those with low haemoglobin concentrations. However, these early hatchlings did not necessarily get more worms: the chicks that hatched from eggs that were laid earlier grew no larger than the later chicks.

Spurred on by the enticing correlations, the team next adopted a classical experimental approach: they rendered some of the maternal starlings anaemic by injecting them with a compound, phenylhydrazine, which bursts red blood cells. The first time they conducted this experiment, in 2010, the results could not have been clearer: the anaemic females took longer to lay eggs, had smaller chicks and, by the time the chicks left the

nest, had fewer than half the number of fledglings. Haemoglobin was clearly crucial for reproductive success.

The next year, 2011, when the authors repeated their efforts, the promising results could not be replicated. The anaemic females laid just as many eggs and successfully raised equally large fledglings. For most scientists, this inconsistency would be a source of frustration. But Fronstin and his co-workers saw something deeper. They realised that in 2011, hatchlings were on average larger than in previous years. Conversely, in 2010 all of the chicks were smaller than usual. They accordingly suggest that the importance of haemoglobin varies with the availability of resources, such as food.

This study represents an impressive unification of mechanistic physiology and reproductive fitness. It further shows that the link is not necessarily simple and opens up new avenues to establish how the importance of oxygen transport by haemoglobin may vary under different conditions in the wild.

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