

Inside JEB 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

## SALMON TOLERANCE TO HEAT AND LOW OXYGEN



Our climate is changing; however, as you sweat out the next heat wave, spare a thought for fish, which also have to cope with these warmer climes. As temperatures increase so do their metabolic rates, which in turn increases their need for oxygen. This problem is compounded by the fact that oxygen supplies become quickly depleted in warmer water by the accelerated growth of other waterborne organisms like algae. If fish are to survive long-term they need to evolve to cope with these challenges. However, evolution can only occur if there is already a significant amount of heritable variation within a population. Moreover, as low oxygen and high temperature are linked, tolerance for either condition needs to be correlated, as Patricia Schulte from the University of British Columbia, Canada, explains: 'If you're trying to select for individuals that do well in both, if everyone who does well in one does poorly in the other, it's a non-starter.' So, is there hope for fish? Is there enough heritable variation for evolution to act? Schulte and her colleagues turned to Atlantic salmon to investigate (p. 1183).

Teaming up with a large aquaculture firm, the team reared 41 salmon families by crossing 41 females each with one of 29 males, with some males fathering up to three families. Two postdocs, Katja Anttila and Rashpal Dhillon, then had the mammoth task of testing over 800 offspring for their tolerance to high temperatures and low oxygen. After acclimatization to the experimental tank, the duo slowly raised the water temperature, carefully monitoring the fish for signs of wooziness, which occurs when the fish has reached its upper limit of heat tolerance. At 23°C some fish were already feeling faint and flopped over, whilst others stuck it out to a toasty 27.5°C. The results were just what they'd hoped for, as Anttila recalls: 'We were thrilled when we started to see that there is huge variability in the temperature tolerance and that the closely related fish (full siblings and half-siblings) resembled each other so much.' This similarity amongst fish fathered by the same male was the essential clue that they'd been looking for that tolerance was heritable.

Next, the team tested how long it would take for dizziness to set in when the salmon was placed in poorly oxygenated water. The team saw a wide variation in tolerance, with wooziness beginning within 22.9–120 min. Again, they found tolerance levels were similar amongst related fish and, moreover, these tolerant families were the same families that had been tolerant to higher temperatures.

So, it seems that salmon meet all the right criteria for evolution to work, but what exactly were the traits that conferred tolerance to these stressors? Schulte reasoned that 'variation would be in the weakest link in the chain, strengthen this and then the whole chain is stronger'. They suspected the heart was the weak link as, in salmon, a large portion of the heart has no direct supply of oxygenated blood and instead scrounges for leftover oxygen in the blood as it passes through the heart. Therefore any variation in oxygen levels could stop the heart working efficiently. Indeed, they found that fish with higher tolerance for heat had larger ventricles. At the protein level, they found more tolerant fish had higher levels of myoglobin, which can act as storage for oxygen. However, variation in these traits doesn't explain all the variability in heat tolerance the team sees, so the investigation for more traits to explain heat tolerance continues. For now though, we can rest more easily knowing that there is at least some hope for salmon's future.

10.1242/jeb.086231

Anttila, K., Dhillon, R. S., Boulding, E. G., Farrell, A. P., Glebe, B. D., Elliott, J. A. K., Wolters, W. R. and Schulte, P. M. (2013). Variation in temperature tolerance among families of Atlantic salmon (*Salmo salar* L.) is associated with hypoxia tolerance, ventricle size and myoglobin level. *J. Exp. Biol.* **216**, 1183–1190.

Nicola Stead

## STREAMING BALEEN TANGLES TO TRAP FOOD

Diving and plunging through the waves to feed, some whales throw their jaws wide and engulf colossal mouthfuls of fish-laden water while other species simply coast along with their mouths agape (ram or skim feeding). Yet, both feeding styles rely on a remarkable substance in the whales' mouths to filter nutrition from the ocean: baleen. Alexander Werth from Hampden-Sydney College, USA, explains that no one knew how the hairy substance actually traps morsels of food. 'The standard view was that baleen is just a static material and people had never thought of it moving or that its function would be altered by the flow of water through the mouth', he says. Werth became fascinated with the substance during his postdoc days, when he worked with the Inupiat Eskimos of



Barrow, Alaska, and decided to find out more about how the flexible material filters whale-sized mouthfuls of water (p. 1152).

Explaining that baleen is composed of keratin – the same protein that makes hair and fingernails – Werth also describes how the protein forms large continually growing plates, each with an internal fibrous core sandwiched between smooth outer plates. Whales usually carry 300 of these structures on each side of their mouths – arranged perpendicular to the direction of water flowing into the mouth – and Werth explains that the plates are continually worn away by the tongue to form bristly food-trapping fringes on the tongue-edge of each plate. In addition, the baleen fringes of the skim-feeding bowhead whale’s bristles are twice as long as the lunging humpback’s. Having obtained baleen samples from the body of a stranded humpback during graduate work at the New England Aquarium and collected samples from ram-feeding bowheads in Alaska, Werth began to compare how well the baleen trapped minute latex beads carried in flowing water.

First, he tested a small section of each type of baleen in a flow tank as he varied the flow speed from 10 to 120 cm s<sup>-1</sup> and altered the inclination of the baleen to the water flow from parallel to perpendicular. Monitoring the fringes and recording how many beads became lodged for 2 s or more, Werth saw that the bristles trapped most beads at the lowest speeds, and as the flow increased the bristles began streaming like hair, increasing the fringe’s porosity and reducing the number of snagged particles: single baleen plates are less effective filters at higher swimming speeds.

However, Werth says, ‘It doesn’t make sense to look at flow across a single plate of baleen, it’s like looking at feeding with a single tooth; you can’t chew anything with just one tooth, you need a whole mouthful.’ So, he built a scaled down rack of six, 20 cm long baleen plate fragments and tested how well they trapped the latex beads.

This time, Werth could clearly see the fringes from adjacent baleen plates becoming tangled and more matted as the flow

increased, trapping the most particles at speeds ranging from 70 to 80 cm s<sup>-1</sup>, which corresponds exactly with the swimming speed of bowhead whales skimming through shoals of copepods. However, when he compared the porosity of the baleen of both species, he was surprised by the similarity of the performances, despite the whales’ different feeding styles.

Having found that baleen filters best at the natural swimming speed of skim-feeding bowheads, Werth is keen to scale up and investigate how full-sized 4 m long baleen plates perform.

10.1242/jeb.087445

Werth, A. J. (2013). Flow-dependent porosity and other biomechanical properties of mysticete baleen. *J. Exp. Bio.* **216**, 1152-1159.

Kathryn Knight

## THE ART OF FINDING PREY: A BAT’S PERSPECTIVE



Many bats have extremely poor eyesight, yet put them in a room with a tiny insect and they will quickly seek it out and gobble it up. When foraging bats have to rely on echolocation to determine the location of their next tasty treat. They produce beams made up of pulses of ultrasound waves and analyse the returning echoes to guide them. Although routine for these bats, it is nonetheless a remarkable feat and one that we haven’t mastered, as Shizuko Hiryu from Doshisha University, Japan, points out: ‘So far, acoustic sensing technology developed by humans using ultrasound cannot detect and track small moving targets like bats do, because the [returning] echoes are very small.’ So how do they do it? Hiryu and some of his students set out to discover the bat’s secret to detecting prey (p. 1210).

The team placed Japanese horseshoe bats, *Rhinolophus ferrumequinum nippon*, in a flight chamber and tempted them into flight by dangling an appetising moth from the ceiling at the other end of the room. As the bats zoomed in on their prey, the team picked up their calls using small ultrasonic microphones located throughout the chamber, and also filmed their aerial trajectory.

Upon release, the bats scanned their new environment by issuing regular pulses lasting 30–40 ms, but as soon as they picked up the tiny echoes from the moth, the pulses lengthened to 70–80 ms and the bats began their pursuit. When the bats were within 1 m, the moth understandably took evasive action, moving considerably in the hope of escaping the hungry bat. The team found that this prompted the bats to respond in two ways; firstly, they produced more closely spaced, shorter (10 ms) pulses and secondly, they broadened the width of their ultrasonic beam by, on average, ±14 deg horizontally and ±17 deg vertically to cover a larger area. In 97% of cases this beam-width broadening was sufficient to cope with the increased movement of the moth and insured that the insect was never out of the range of the bat’s ultrasonic call. Furthermore, in cases where the moths seemingly gave up hope and failed to move at all, the preying bats likewise failed to widen their calls.

At first, Hiryu thought that the appearance of beam expansion was due to an artefact in their microphone array, but after careful re-evaluation the team are sure that these bats are definitely widening their beams as they approach their prey. However, it remains a mystery how these bats adjust their beams. The ability to vary beam width has previously been seen in bats that emit calls where ultrasound waves vary in frequency throughout the pulse, called frequency modulation (FM). As sound waves with lower frequencies spread further, these bats just lower the maximum frequency reached during their pulse to widen their beam. Japanese horseshoe bats, however, emit their pulses in a slightly different way, incorporating two FM elements interspersed by a section of waves with a constant frequency (CF). When the team analysed changes in the FM elements of the horseshoe bat’s calls they didn’t see a large enough drop in maximum frequency to explain the beam-width expansion. CF–FM bats must therefore use a different way to modulate their beams. As horseshoe bats emit their calls through their nostrils, the team suggests that the orientation of their noseleaf – the tip of the nose – may control beam width.

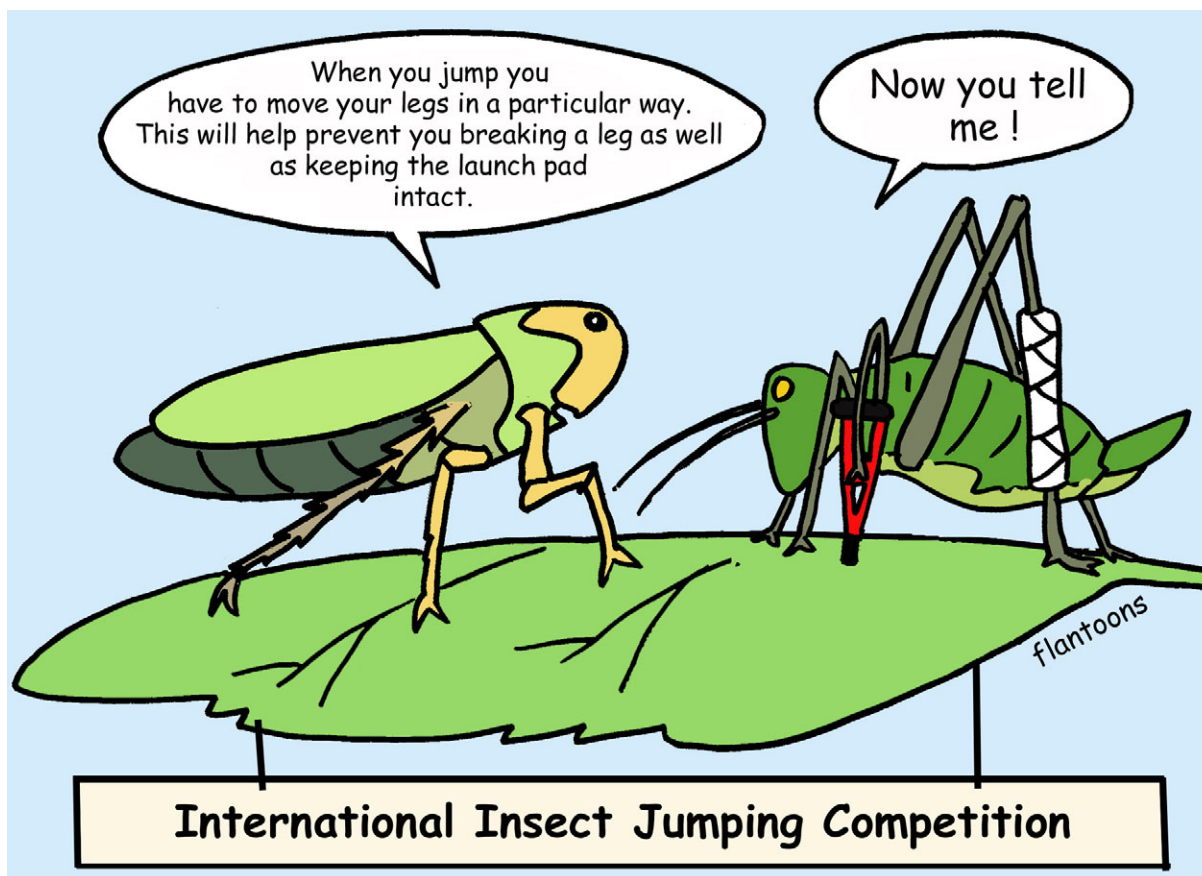
Whilst we still don’t know exactly how bats initially detect minute echoes, Hiryu’s study has unveiled for the first time one of the bat’s secrets for capturing moving prey.

10.1242/jeb.085530

Matsuta, N., Hiryu, S., Fujioka, E., Yamada, Y., Riquimaroux, N. and Watanabe, Y. (2013). Adaptive beam-width control of echolocation sounds by CF–FM bats, *Rhinolophus ferrumequinum nippon*, during prey-capture flight. *J. Exp. Biol.* **216**, 1210-1218.

Nicola Stead

BENT LEGS BEAT BREAKAGES DURING TAKE-OFF



As an insect hops from leaf to leaf looking for food or jumps away to escape a peckish predator, the last thing it needs is to either break its leg or stumble because the supporting leafy surface collapses. However, in order to defy gravity, insects need to generate high accelerations as they push off and this in turn requires strong forces that act on both the insect's legs and the leaf. So, how do insects generate enough acceleration to become airborne but not produce too much force that would break either their legs or their launch pads? Cesare Stefanini from The BioRobotics Institute, Italy, and his colleagues decided to investigate (p. 1270).

The potentially damaging forces mainly occur during the initial take-off phase, from when the insect readies itself to jump to just after it's airborne, and with take-offs

occurring in as little as 1 ms, they are not easy to capture. Undaunted, Stefanini turned to the green leafhopper, *Cicadella viridis*, which takes off in a relatively leisurely 5.6 ms. By filming their sky-bound launches at a rapid 8000 frames s<sup>-1</sup>, the team were able to calculate that it took off at an average velocity of 0.9 m s<sup>-1</sup> with a near-constant acceleration rate of 152 m s<sup>-2</sup>.

This near-constant acceleration rate also means that there is constant force being exerted at the foot-ground interface. However, muscles, which power the jump, are naturally elastic and cannot provide a constant force. In fact, peak forces that are generated by the muscles are high enough to damage the thrusting insect's leg or the leaf. Using the data from their videos, the team calculated that breakages are prevented

because of the way the leafhopper's legs moves its legs. As energy is released from the contracted muscles in the thorax, the femur portion of the leg rotates and transmits the motion to the tibia. In doing so it converts the variable muscular force to a constant force acting on the tibia, which pushes off the ground without damaging the leg or the launch pad. So, good posture is key for jumping.

10.1242/jeb.085944

**Bonsignori, G., Stefanini, C., Scarfogliero, U., Mintchev, S., Benelli, G. and Dario, P.** (2013). The green leafhopper, *Cicadella viridis* (Hemiptera, Auchenorrhyncha Cicadellidae), jumps with near-constant acceleration. *J. Exp. Biol.* **216**, 1270-1279.

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