Keeping track of the literature isn't easy, so Outside JEB is a monthly feature that reports the most exciting developments in experimental biology. Short articles that have been selected and written by a team of active research scientists highlight the papers that JEB readers can't afford to miss.

Outside JEB

NUTRITIONAL ASSESSMENT

THE SWEET MEMORIES OF A FRUIT FLY

We all have the luxury of knowing what foods are good for us. Our parents' telling us to eat our greens allows us – however unwillingly – to find the nutrients we need to survive. But how do other animals find out what foods to eat, without being able to rely on the advice of others?

Taste plays a major role in this process. Sweetness indicates the presence of sugars, which can be nutritionally valuable. However, this indicator is unreliable because not all sugars can be metabolised, and to make matters worse, not all nutritious sugars are sweet. So how can an animal improve on this? Two teams of researchers have addressed this question by asking whether the fruit fly *Drosophila melanogaster* is able to assess and remember the nutritional value of sugars independently of how they taste.

Both teams first wanted to see which sugars are actually nutritious to the flies. To do this they looked at how long flies survived when placed in a vial that contained a source of a particular sugar.

They found that sugars commonly found in the flies' natural food source of soft rotting fruit were able to sustain the flies very well, but other sugars were not. However, a compound called sorbitol also sustained the flies, even though flies do not perceive it as sweet. The teams therefore showed that flies eat things that they do not consider tasty in order to survive. So do flies actually learn to eat tasteless food, or do they simply eat everything they can find in the hope of getting lucky? In order to find this out the teams performed a series of elegant behavioural experiments to test which compounds the flies prefer to eat.

Both teams indeed found that, even though flies like sugars that are sweet, they will prefer to have a nutritious meal. This shows that flies are able to assess the nutritional value of sugars. Their experiments also showed that flies very quickly acquired a memory of the nutritional value of a sugar and retained it for at least a day. However, when the researchers repeated the experiments using flies that have defective synapses, the flies failed to learn the nutritional value of a sugar. This showed that the system that assesses and remembers nutrient quality must be found within the brain.

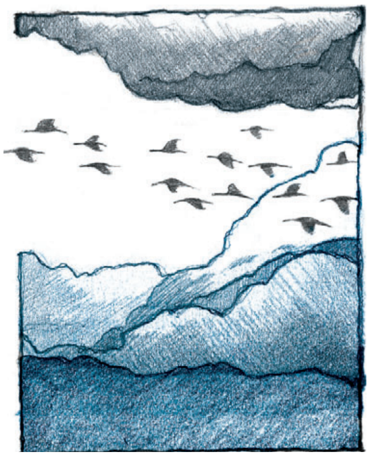
The authors of the two studies have shown that fruit flies are able to assess and remember the nutritional value of sugars in a process that occurs after the food has been ingested. This mechanism involves cells in the brain telling the fly that, whatever it is eating, it is doing the fly good. The next step – presumably already underway – will be to locate these cells and find out how they are connected within the brain.

10.1242/jeb.049908

Burke, C. J. and Waddell, S. (2011). Remembering nutrient quality of sugar in *Drosophila*. *Curr. Biol.* **21**, 746-750.
Fujita, M. and Tanimura, T. (2011). *Drosophila* evaluates and learns the nutritional value of sugars. *Curr. Biol.* **21**, 751-755.

Maarten Zwart
University of Cambridge
mfz20@cam.ac.uk

FEEDING



HUMMINGBIRD TONGUE TIPS TWIST TO TRAP NECTAR

Few sights capture nature's elegance and inventiveness as keenly as a flitting hummingbird pausing momentarily in mid-air to feed on a flower's nectar. The stillness of the hovering itself demands awe, and the biomechanics of hummingbird flight have rightly been at the center of a number of recent high-profile studies. But if you can look beyond the aerodynamic intricacies involved, another mystery becomes apparent; that of nectar extraction itself. Recent work published in the *Proceedings of the National Academy of Sciences* by Alejandro Rico-Guevara and Margaret Rubega from the University of Connecticut, USA, is soon to radically change our understanding of how hummingbirds feed.

Tongues are important for fluid consumption in a number of tetrapods (consider a lapping cat or dog), and nectar-feeding hummingbirds are no exception. For nearly 200 years the tongue's role in hummingbird feeding was recognized as crucial, but the mechanism involved was debatable and theories invoked suction and, more popularly, capillary action as potential driving forces. Hummingbird tongues possess two grooves running from their tip back toward their base, and the idea behind the capillary model is that when the tongue tip is placed into nectar the fluid is passively drawn through the grooves toward the mouth *via* capillarity. This passive mechanism involving the fluid's own properties (e.g. surface tension) is central to foraging and energy balance models used by physiological ecologists studying hummingbirds; however, recent empirical work is inconsistent with capillary action as the driving force behind nectar feeding.

To find a new explanation, Rico-Guevara and Rubega performed detailed morphological studies of tongues from 20 species of hummingbird and used high-speed video to record tongues from animals of 10 hummingbird species moving in and out of nectar *in vivo* and post-mortem. Hummingbird tongues are bifurcated at the tip, which is covered with lamellae that help to form the previously mentioned grooves on either side of the tongue. Prior to feeding, the tongue tips are held together and the lamellae are tightly furled, making the groove appear like a flattened tube in cross-section. Upon entering nectar, the tongue tips spread apart and the lamellae unfurl, essentially opening the tongue grooves wide, allowing them to fill with nectar. When pulled out of the liquid, the tongue tips twist about their long axes, and the lamellae roll inward, furling back up again and creating a tube-like structure with the nectar trapped inside it. This re-furling of the lamellae happens just as they pass across the liquid–air boundary. The authors suggest that these lamellar movements create a 'lingual seal', which prevents nectar from leaking out of the tongue as it is pulled back into the mouth.

This whole process can happen in about 50 ms and the movements at the tongue tip appear to require no muscular work. Post-mortem tongues perform just as well as those *in vivo*, indicating something special about the structure of the tongue itself and the way it responds to physical forces at the air–nectar interface as it is pulled back into the mouth. The authors show that the structural bases of this nectar-trapping mechanism are found in species from all major clades of the hummingbird family, indicating the likelihood of its widespread presence as a means of feeding. Whether this fascinating fluid-trapping design can be incorporated into biomimetic technology remains to be seen, but until then at least we should appreciate that hummingbirds can take advantage of it.

10.1242/jeb.049924

Rico-Guevara, A. and Rubega, M. A. (2011). The hummingbird tongue is a fluid trap, not a capillary tube. *Proc. Natl. Acad. Sci. USA* **108**, 9356-9360.

Gary B. Gillis
Mount Holyoke College
ggillis@mtholyoke.edu

THERMOREGULATION

SOME EGGS LIKE IT HOT

Compared with endotherms, homeotherms have it easy: environmental temperature has little effect on our biological processes as we generate our own warmth internally. In contrast, ectotherms – which don't intrinsically maintain a constant body temperature – must constantly cope with varying thermal conditions, seeking warm or cool areas to maintain their body temperature within the optimal physiological range. But how do embryonic reptiles cope with fluctuating temperatures? It was generally accepted that they could not behaviourally thermoregulate. First, the embryos are bound within an eggshell, preventing any major relocation. Further, the machinery required to both detect thermal heterogeneity and relocate to a more favourable environment was thought to be lacking in their early life stages. However, Wei-Guo Du, Bo Zhao and Ye Chen from Hangzhou Normal University, China, and Richard Shine from the University of Sydney, Australia, challenged this point of view in their recent *Proceedings of the National Academy of Sciences* study. The authors specifically assessed the capacity of turtle embryos to change their position in the eggshell depending on the positioning of the heat source outside of the egg.

The team initially decided to assess whether significant temperature gradients could occur on the surface of the eggs. They observed that the part of the eggshell closest to a heat source could be a much as 1°C warmer than the opposite part of the egg, thereby definitely establishing that thermal heterogeneity occurs within these eggs.

Next, Du and colleagues exposed turtle eggs in their first month of development to a heat source coming from the side or from above. The authors assessed the initial position of the embryo in the egg by candling (transmission of bright light through the egg) and then periodically sampled eggs to dissect and record the embryos' displacement within the egg according to their initial position. In both laboratory and simulated nest settings, the team discovered that the 'immobile' turtle embryos were indeed moving around in their eggs, specifically repositioning themselves closer to the heat source. In addition, when they shifted the heat source midway through their experiment from a lateral to a dorsal position, the embryos closely followed the heat source thereby providing further support to their initial results.

This elegant study certainly shows that even early in their development, turtles can behaviourally thermoregulate by moving around in their eggshell depending on the thermal gradient in their environment. This behavioural adjustment could provide them with a strong selective advantage when it comes to their development. Indeed, minute differences in temperature can have a drastic effect on developmental rates during early life stages. Further, this study opens up a suite of questions regarding this remarkable feat in turtle embryos as these results suggest that the structures necessary to elicit this behaviour (sensing a temperature gradient) and to accomplish it (locomotory capacity) are in place very early in turtle development, certainly warranting further research.

10.1242/jeb.049890

Du, W. G., Zhao, B., Chen, Y. and Shine, R. (2011). Behavioral thermoregulation by turtle embryos. *Proc. Natl. Acad. Sci. USA* **108**, 9513-9515.

Chris Le Moine
University of Ottawa
clemoine@uottawa.ca

SWEET MEAL PROVES TOO GOOD TO BE TRUE FOR CATERPILLARS

Plants often avoid predation by producing chemicals that are detrimental to the herbivores that might try to eat them. For example, tiny hairs on the tobacco leaf (*Nicotina attenuate*) produce and secrete viscous liquids containing *O*-acyl sugars (AS) that are known to inhibit growth in certain insect larvae. Insects such as aphids, white flies and spider mites have each been shown to suffer from eating plants that produce AS. Because AS are known to effectively repel many herbivores, Alexander Weinhold and Ian Thomas Baldwin, from the Max Plank Institute for Chemical Ecology, were surprised when they recently found that one species of caterpillar, *Manduca sexta*, actually preferred to feed on small hairs flavoured with AS for their first meal after hatching. Weinhold and Baldwin were keen to test whether *M. sexta* suffered as a result of feeding on the usually lethal *N. attenuate* plant. The pair first measured the larvae body size and viability of caterpillars fed on AS-containing leaf hairs compared with caterpillars that ate AS-free leaves. They found that larvae fed from each food source grew equally well, and that rather than being a defensive mechanism, the plants provide a sugary first meal that was preferred by the growing caterpillars.

Based on the fact that many herbivore-damaged plants have been shown to produce chemicals that attract the herbivore's natural enemies, Weinhold and Baldwin carefully measured the profile of the odour produced by the caterpillar's faeces after they had been fed leaves that had been washed to removed the AS or leaves that retained their AS. The duo found that the food type directly affected the odour profile in the waste produced by the caterpillar. The caterpillars that consumed AS-containing leaves produced excretions with a strong odour, but they quickly lost the odour when the diet was changed to an AS-free food source.

Knowing that predators often use faecal odour to locate their prey, the team flavoured rice with the caterpillar odour and then allowed ants to collect the flavoured and unflavoured rice and return with it to their nests in order to identify the species that prey on the caterpillar. After counting the number of scented and unscented grains in the nests, Weinhold and Baldwin identified five ant nests all belonging to the same species of rough harvester ant, *Pogonomyrmex rugosus*. The team then placed caterpillar faeces that contained AS, and faeces that did not, on top of 20 cm wooden sticks and found that the *P. rugosus* ants preferentially climbed the sticks with fresh AS-containing excrement.

The authors conclude that while *N. attenuate* does not use AS in the typical way – as a direct defence against being eaten –consuming the sweet AS-containing leaf is not without penalty. Weinhold and Baldwin found that the resulting scent caused by eating AS indirectly helps the natural predators of caterpillars to locate them. So ants benefit from *N. attenuate*'s AS-laced leaves: the odour-labelled caterpillar proves to be an appetizing GPS for the ground-hunting ant to find its prey.

10.1242/jeb.049916

Weinhold, A. and Baldwin, I. T. (2011). Trichome-derived *O*-acyl sugars are a first meal for caterpillars that tags them for predation. *Proc. Natl. Acad. Sci. USA* **108**, 7855-7859.

Katherine M. Parisky
Brandeis University
kparisky@brandeis.edu