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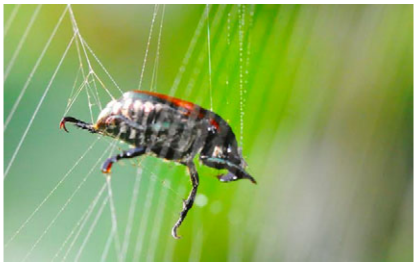
INSIDE JEB

UVB tailors spider glue strength



A beetle trapped in a spider's web. Photo credit: Brent D. Opell.

Compared with natural adhesives, man-made glues are puny: often coming unstuck and only working on clean dry surfaces, their uses are limited. Meanwhile, geckos' sticky feet never become exhausted and barnacles weld themselves irreversibly to any wet surface; although the adhesive champions must be the spiders. 'We're interested in the [spider web] glue because it is an incredibly tough material with the potential to inspire new glues with similar properties', says Sarah Stellwagen from Virginia Tech, USA. Adding that spider glues are stretchy as well as sticky and that they work well in both wet and dry conditions, Stellwagen and her colleagues Brent Opell and Mary Clouse decided to find out what effects ultraviolet (UV) radiation might have on the glue. Knowing that UV radiation comes in two bands, UVA and UVB, both of which can have damaging effects, Stellwagen wondered whether spider web glue was enhanced or degraded by UVB and whether the glues of spiders that live in dark conditions was more vulnerable to UVB damage than the glues of spiders with sunnier lifestyles.

Fortunately, Stellwagen has been fascinated by spiders ever since her twelfth birthday when she became the proud owner of a pet tarantula, Clawdia; shooing arachnids away from their webs – to enable her to take the structures back to the lab – did not concern her. She also explains, 'We needed full large webs with the largest droplets possible for testing and consistency, so we needed all of the spiders to be at the same life stage'. Working with Opell and Clouse, Stellwagen collected the webs of spiders that build their webs in locations ranging from full sunlight (the yellow garden spider) and bright and dark conditions (the orchard spider) to species that construct webs in varying degrees of shade: from the arrowhead spider, which prefers shady locations with occasional glimpses of sun, to the spined macrathena, which lives in dense shade and the nocturnal barn spider.

Back in the laboratory, Stellwagen extracted lengths of sticky spiral silk and exposed them to doses of UVB radiation (for 1–4 h). Photographing the glue droplets, Stellwagen compared the volume before and after UVB exposure to find out if the radiation had damaged the small molecules in the glue that absorb moisture from the atmosphere to keep the droplet hydrated. However, the droplets did not change size, so the radiation had not affected the molecules.

Next, Stellwagen measured the glue droplet's toughness – the amount of energy that the glue can absorb – by securing the droplet to a metal pin and slowly pulling it back. This time, UVB radiation had a clear effect. The glue of both the spined macrathena (dense shade) and the nocturnal barn spider was severely damaged by UVB – the toughness of both was reduced by at least half. However, the arrowhead spider's glue was unaffected by the radiation. Meanwhile, exposure to UVB was beneficial for the glue of spiders that lived in bright and less shady locations; the toughness of the yellow garden spider's glue increased more than three times after the highest UV dosage and the orchard spider's glue toughness doubled. Yet the orchard spider's glue was the only one that had become tougher after being kept in the dark, suggesting that it cures over time.

'Spider glues are tailored to perform in specific environments in more ways than one: humidity, temperature and now UVB all result in performance differences,' says Stellwagen, who is keen to find out how much UVB the most resistant glues can take before they begin to fail.

10.1242/jeb.129692

Stellwagen, S. D., Opell, B. D. and Clouse, M. E. (2015). The impact of UVB radiation on the glycoprotein glue of orb-weaving spider capture thread. *J. Exp. Biol.* **218**, 2675-2684.

Kathryn Knight

Muscle powers caddis fly take-offs

An adult caddis fly. Photo credit: Malcolm Burrows.

Malcolm Burrows is always on the look out for intriguing insects, especially if they jump. From fleas and locusts to praying mantises, Burrows has captured the elegant acrobatics of species from across the globe with his high-speed camera, detailing every element of their graceful launches. Some of the species that he has scrutinised have even come from his back garden. 'I set up a light and an old white bed sheet on my washing line to attract moths,' says Burrows, who was intrigued when the caddis flies that had blundered into his trap began jumping to escape as he attempted to collect them. 'We could find no previous reports of this behaviour,' Burrows recalls, so he and Marina Dorosenko transported the insects to his laboratory at the University of Cambridge, UK, to learn more about their jumping technique.

Unfortunately for Burrows, the caddis flies were less cooperative once in the lab. '[We had] to get them to jump in the appropriate direction so that we could get high-speed videos… that were in focus and that would enable us to understand the sequence of leg movements', he explains – adding that the insects had a tendency to escape, ending up lodged in light fittings and other nooks. However, after months of patiently encouraging the

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insects to launch themselves into the air, Burrows and Dorosenko successfully captured 90 take-offs from three species ranging in size from 4.5 mg up to 70 mg.

Scrutinising the movies, the duo could see that the insects used two strategies to get themselves into the air. In the first, the caddis flies began pushing down with both rear pairs of legs 10 ms before take-off, lifting the front legs off the ground 5 ms into the launch preparation. However, Burrows and Dorosenko were surprised to see that even though the rear legs were longer than the middle legs, they lost contact with the ground first, leaving the middle legs to push down and provide the final thrust. The duo was also intrigued to see the caddis flies deploy their wings during a third of the leaps, spreading them wide before partially depressing them while the legs prepared to push off – although the wings were not fully depressed at lift off, probably to avoid crashing into the ground.

So, how do the insects power these leaps? Burrows explains that jumping is physiologically challenging because animals have to produce large amounts of power at high speed. However, muscles cannot satisfy both demands simultaneously. To resolve the paradox, some insects slowly store energy in catapult structures in the exoskeleton – which is released explosively at take-off – while others coordinate several muscle-powered limbs to push off more gently. Wondering which mechanism the caddis flies use, Burrows and Dorosenko calculated the power required for the take-off and found that it ranged from 226 to 343 W kg^{-1} – well within the range of muscle. So, the caddis flies power their launches by direct contraction of their leg muscles.

But why don't caddis flies resort to using an explosive catapult mechanism when it could give them a faster take-off? Burrows suspects that the answer could lie in the insect's environment. Explaining that catapult-powered take-offs exert high forces on surfaces during take-off, Burrows suggests that caddis flies may have opted for the more sedate muscle-powered take-off, to distribute the take-off forces over more limbs and longer times, and allow them to take to the air from more flexible structures, such as the leaves and petals of plants that skirt the watercourses where they lay their eggs.

10.1242/jeb.129718

Burrows, M. and Dorosenko, M. (2015). Jumping mechanisms in adult caddis flies (Insecta, Trichoptera). *J. Exp. Biol.* **218**, 2764-2774.

Kathryn Knight

Bumblebees don't push acceleration limits

Bumblebee in flight. Photo credit: Andrew Mountcastle.

Stuck in our concrete box cities, we can sometimes forget just how complex the natural world is, but from the perspective of a foraging bumblebee, it's a convoluted three-dimensional maze. Whether negotiating a tree's foliage or waving grass in a meadow, bumblebees constantly have to deal with clutter in their surroundings, '[But] we still know relatively little about how insects and flying animals generally deal with complex natural environments', says James Crall from Harvard University, USA. Intrigued by the challenges that these intrepid insects encounter on a daily basis, Crall and his colleagues, Sridhar Ravi, Andrew Mountcastle and Stacey Combes decided to find out which factors restrict bumble bees as they manoeuvre past obstacles and how much their size affected their manoeuvrability.

'During previous research we found that… bees tend to move more laterally than vertically,' explains Crall, so the team designed two flight tunnels – one with horizontal obstacles that forced the insects to fly a wavy up-and-down path through the obstructions and a second with vertical structures that forced them to dodge from side to side – to test their horizontal versus their vertical manoeuvrability. Although Crall admits that wrangling the bees was even trickier: 'It's always a challenge to get regular, natural flight behaviour out of insects in laboratory environments', he shrugs. But then the team placed the tunnel between the bee's hive and the outside world, forcing them to negotiate the obstacles every time they went foraging.

Once everything was in place, Crall began filming the insects' manoeuvres in three dimensions with a pair of high-speed video cameras before analysing the complex flight paths. However, the team was surprised when their theory that the bees were more agile dodging sideways than vertically did not hold out. Explaining that the bees' main goal is to use as little energy as possible while foraging, Crall used the length of time that it took the insects to complete the route as a measure of each individual's performance: 'as they would say, "time is honey"', he chuckles. However the bees were no more speedy negotiating obstacles when they had to swerve from side to side, than when weaving up and down.

Crall also recorded the insects' maximum acceleration, the curviness of the path that they followed and the number of times that they had to back-up and take another run past an obstruction to avoid a collision as they swerved along the tunnel. However, the bee's ability to accelerate hard didn't improve their transit time and larger bees seemed to bumble along more slowly than their smaller nest-mates; they chose a more cautious approach, taking pains to avoid collisions by backing away from objects before negotiating them and giving obstacles a wider berth.

'Bumblebees are probably performing well below their mechanical and physiological limits in order to minimize collision risk', says Crall, adding, 'This probably makes sense, since in natural environments flying animals are balancing a lot of constraints, such as risk of collision, predation, navigational and sensory challenges'. And now Crall is keen to find out whether the bumblebee's performance improves with familiarity. 'Maybe as bees learn an environment better, they fly through it faster and faster until they eventually become limited by acceleration', he says.

10.1242/jeb.129700

Crall, J. D., Ravi, S., Mountcastle, A. M. and Combes, S. A. (2015). Bumblebee flight performance in cluttered environments: effects of obstacle orientation, body size and acceleration. *J. Exp. Biol.* **218**, 2728-2737.

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