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RESEARCH

Nature's Own Version of Superglue

Understanding how insect feet adhere to slippery, wet surfaces has been a centuries-long quest

By Leslie Pray

Image courtesy of Isle of Wight History Centre

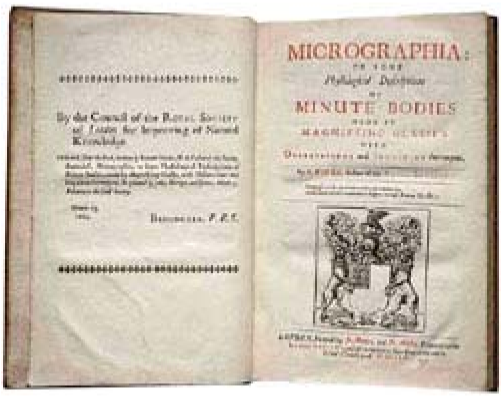
A close-up picture of the common fly.

"The foot of a fly is a most admirable and curious contrivance, for by this the flies are enabled to walk against the sides of glass, perpendicularly upwards, and to contain themselves in that posture long as they please; nay, to walk and suspend themselves against the undersurface of many bodies, as the ceiling of a room, or the like ... its mechanism consists principally of two parts, that is, first its two claws, or tallons, and secondly, two palms ..." 1

Robert Hooke, 1664

Scientists have studied insect feet ever since Hooke drew the first microscopic images of fly "tallons" and "palms" nearly 400 years ago. "It's a very old subject," says entomologist Walter Federle of the University of California, Berkeley, and leading author of a recent study on how Asian weaver ants (Oecophylla smaragdina) and honeybees (Apis mellifera) grip smooth surfaces and even walk upside down.

Image courtesy of Isle of Wight History Centre



An Early Pioneer: An example of the engravings from Robert Hooke's "Micrographia"

Early on, Hooke and fellow micros- copist Antonie van Leeuwenhoek were more concerned with what the pads looked like rather than how they worked, Federle says. But by the 19th century, scientists became more interested in function and experimenting with insect feet to discover how insects could grip with such tenacity.

And they are still experimenting. Scientists such as Federle want to know what it is about those adhesive pads, called arolia, that allow insects to run along slippery, waxy plant leaves and stems without falling down, even when bombarded by raindrops 10 times their size. Not only do these studies increase understanding of insect biology, but they are also helping engineers design better robots.

It's All About Control

The arolia are the ants' and bees' equivalent of the fly palms that Hooke described. They are soft, cuticular sacs positioned between the claws, and they secrete a fluid that yields a very powerful sticking capability. But "the most interesting thing about the arolia," says Federle, "is the fact that they can be moved." Insects can run swiftly even in the face of forces more than 100 times their body weight, which means that surely the insect must somehow be controlling arolium movement, Federle explains. The question is, how?

"There is a lot of excellent information about arolium movement in the honeybee," says Stanislav Gorb of Tubingen's Max Planck Institute for Developmental Biology in Germany, referring to studies conducted in the mid-20th century.2 "However, many details about the movement are unclear because of the absence of high-speed recordings in the 1950s and 1960s."

Federle teamed up with biologists Elizabeth Brainerd of University of Massachusetts, Amherst, the late Thomas A. McMahon of Harvard University, and Bert Hölldobler of the University of Wurzburg, Germany. Using a high-speed video camera mounted on a dissecting microscope, these researchers recorded the arolia's movements as insects walked upside down on a microscopic slide.3 The researchers found that the arolium itself does not contain any muscles, but it is indirectly connected to a single long muscle that runs the length of the tarsus. With the high-speed video camera, Federle and his colleagues observed how "this muscle controls not only claws but also adhesion pads in a quite complicated way," says Federle. "Several movements are controlled by this single muscle. The interesting thing is that all of these movements do not occur at the same time."

With each step, the claws are extended first so that they are the first part of the foot that actually touches the surface. They then immediately retract, and the arolium unfolds and inflates with blood so that it protrudes between the claws and touches the surface. At the end of the step, which takes only a fraction of a second, the arolium deflates and folds back and the claws extend again.

Although an insect can actively fold and unfold its arolia as it is moving, the arolia can also move independently without any input from the insect. Indeed, one of the most important things learned from this study, according to Federle, is that two different mechanisms of arolium motion exist: active and passive. By pulling amputated legs across a glass surface, the researchers recorded this passive response to a pull on the leg. Passive mechanical action does not require any neuronal feedback, which means that the action happens at the same time that the force is exerted. It is faster than the kind of reflex that requires neuronal control. "This makes sense biologically," says Federle, "because very often, very large forces are acting on these animals, like wind or raindrops." Without this passive action, the insect could not respond in time and would likely be bounced off the plant.

Image courtesy of E.N. Moudrianakis

Gripping Gear: A scanning electron micrograph of the Drosophila foot with claws and suction cups.

Because the arolia hold on and detach very easily, they may serve as a model for microrobotic engineers, notes Federle. Indeed, insect biomechanics is a field ripe for design engineers, particularly when it comes to miniaturization. "Microscopical engineering devices often require completely new designs if compared with macroscopical systems," says Max Planck's Gorb. "At small dimension, adhesion force plays a considerable role in mechanical behavior." Because of this, engineers have a difficult time making microrobots that move. "The problems these engineers have are quite similar to these problems that insects have," says Federle, and they may have something to gain by letting the insects do the walking. Gorb agrees: "Insects and other animals have solved some problems in their evolution, so why not look for engineering design solutions in the living systems?"

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References

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