Decoding an Insect’s Sensory World

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When Shannon B. Olsson first moved to Bangalore, India, to start her lab at the National Centre for Biological Sciences at the Tata Institute of Fundamental Research in 2014, she was struck by all the curious foods in the city’s markets. “There are all these unfamiliar gourds—bitter gourds, elephant gourds—that I didn’t know what to do with,” she says.

Having lived and worked on three continents, Olsson had certainly sussed out sources of food in novel environments before. But it got her thinking about the insects she studies—hoverflies. This family of insects lives in a wide range of different habitats, including tropical, alpine, and subarctic regions. How do they know which flowers are food, when flowers look and smell so different in areas like India and Sweden and the U.S.?

Karin L. Nordström, a neuroscientist at Flinders University who studies how insects visually perceive their world while moving—seeing on the fly, as it were—had a related question. Nordström uses wild hoverflies for her experiments, and while catching them she noticed that they would all go to the same flowers—one that to her looked identical to the ones right next to them, which the hoverflies routinely ignored.

Hoverflies are one of the most prominent pollinators on the planet behind bees, but unlike bees they are solitary; once the larvae hatch, they are on their own, with no one to teach them what food sources to prefer. Whether it’s an individual fly choosing from an array of flowers or a worldwide preference by the flies for specific cues, Olsson and Nordström hypothesized that these insects must have an innate template that helps them find flowers wherever they are. They set out to identify what exactly draws these insects to their food.

Such work asks theoretically fascinating questions about insect perception, but it also has a practical dimension. The decline in bee populations and the threat it poses to farming has been big news in the U.S. and Europe, and many of the studies on boosting pollination come from those regions. But nobody has studied whether recommendations derived in those places are relevant in India. Indeed, Olsson says, “very little research even compares the U.S. to Europe, so our cross-continental study is useful for that understanding.”

CREATURE CHEMISTRY

As a chemical ecologist, Olsson investigates the chemical cues through which organisms communicate with each other and with their environment: how insects attract mates, detect food sources, and repel predators—a cardinal triad of activities she refers to as “love, hunger, and fear.” The molecules that animals and plants use to perform them constitute a kind of universal language, she says.

At the same time, chemical ecology is a field with a dizzying array of variables. “Chemical communication is not a static thing; it depends on so many factors,” says Sylvia Anton, a neuroethologist at the French National Institute for Agricultural Research in Angers who studies how insects detect olfactory cues. Tremendous interspecies differences exist, such as in the pheromones they emit and how sensitive insects are to detecting chemicals wafting on the wind. “You start all over with every insect you work with,” Anton says.

But Olsson is looking for universal elements—common threads in how such communication takes place, Anton says. A key element of that search, she adds, is that Olsson
weaves together a multitude of techniques, combining classical chemistry and field-based ecology with 21st-century innovations such as virtual reality and three-dimensional printing.

“Chemical ecology is by its very name an inherently interdisciplinary field,” Olsson says. “We are simply bringing it to the next level.” Above everything, Olsson explains, her work is inspired by the holistic viewpoints of 19th-century naturalists and the practice of observing—without preconceptions—how organisms interact in their environment before attempting to quantify behaviors in the lab. Thomas Eisner, who was one of her Ph.D. advisors at Cornell University and is considered a founder of the field of chemical ecology, always exhorted Olsson to start in nature. Controlled lab experiments allow you to get down to single genes or single molecules, Olsson says. But without such field observations, “you lose sight of the fact that living organisms exist in a complex matrix.”

FLOWER FAKEs

So Olsson and Nordström set out to observe hoverflies on their turf, before bringing them into the lab. The researchers spent weeks in the tropical climate of Bangalore, the mountains of North Sikkim in northern India, and in the near-subarctic meadowlands of Uppsala, Sweden, observing and recording a swath of data from 112 flowers that hoverflies visited and 41 they did not.

The researchers used a light meter to capture flowers’ illuminance, a spectrophotometer to quantify color, and a specially designed sensor to capture the humidity, temperature, and carbon dioxide level surrounding each flower. They also took photographs to record the size and shape of the flowers and collected in silicone tubing a chemical snapshot of the volatiles given off by the flowers for later analysis in the lab using gas chromatography and mass spectrometry. They then analyzed these measurements using multivariate statistics to determine which of these parameters influenced the insects’ preferences. Some of the cues seemed to be more attractive in just one of the environments, but others appeared to draw insects at all three locations.

On the basis of these preferences, the duo and their colleagues created artificial lures made from colored paper stuck either on toothpicks or on tubes releasing volatiles. These lures included combinations of features that the hoverflies liked more and ones that they liked less. The team also made three positive controls that tried to mimic a specific flower from each site that was particularly attractive there and therefore had the best chance of drawing flies at that location, and a general negative control lure cut from black paper, which was unlikely to draw flies anywhere. They returned to each site, starting with North Sikkim, and planted the false flowers in the ground. To their great surprise, the hoverflies flew to the positive controls and to some of the test flowers. “I didn’t think it would work. I had zero faith in it,” Nordström says. “They are so fake.”

“Sometimes it started raining, and sometimes cows walked through our field sites, so we had to have a hundred or so of each” of the lures, Nordström says. One of the fake flowers—the positive control from Sikkim, a small yellow one with flat petals and a combination of five volatiles—proved to be a kind of überlure that attracted the flies at all three locations.

“That study is really asking, ‘Do these guys have universal preferences that are context independent, or do they make decisions based on where they are and what’s available in the flower market?’” says Robert A. Raguso, a chemical ecologist at Cornell. The answer is both: Even though attractive flowers have distinct signatures that vary by location, a cluster of region-independent cues combined from different flowers can do the job—even though the combination did not correspond to real flowers in any of the three locations.

The two collaborating teams are drilling down further to better understand the flies’ preferred cues. “We found one model that works everywhere, and now we are trying to extract what exactly about it is attractive,” Olsson says. “Is it the color? Is it the smell? Is it the certain chemicals it has? Is it a combination?” The idea, she says, is to parse the cues to determine the minimum amount of information that a flower must contain for a hoverfly to recognize it as a flower of choice. She compares it to the way that a smiley-face drawing is the simplest possible representation of a face. “Two dots and a semicircle—that’s a face to everybody,” Olsson says. What’s the smiley-face for a fly?
In a new experiment, she and Nordström are creating a new set of fake 3-D-printed flowers, which are easier to standardize than ones made of paper. Their aim is to deconstruct the cues that made up the all-around attractive yellow Sikkim flower to see which components of that fake flower are most important for the flies’ preference. The smell consists of five volatile components—6-methyl-5-hepten-2-one, p-cymene, 2-ethyltoluene, limonene, and undecanal—so they can tweak the combination in the lab, for example. They can change the color—or even remove it completely. After pinning down the behavioral component, they will investigate how these insects’ brains perceive the minimal set of cues that equals “flower” by imaging the flies’ brains in response to seeing these cues. They hope to track these responses to specific regions, and perhaps even specific neurons, in the hoverfly brain.

As they try to understand what combination of sensory cues marks the essence of a flower for hoverflies, a natural next question is “What about other species?” Olsson’s lab is using virtual reality to deconstruct the cues that attract parasitic insects called apple flies to apple trees. By placing a fly in the virtual environment, she can observe the beating of its wings as it tries to fly toward virtual cues. These visual, chemical, wind-pattern, and other cues mimic what the insect would experience outdoors, and Olsson’s team can mix and match them to see which are most salient. If a tree smells like apples but has no apples in it, would the fly still approach it? The setup allows them to push past real-world constraints in order to distinguish trees from apples, or smells from their source. Initially, she wondered whether the cues would be too confusing, but in fact the insects took to the setup quite well. “We’re taught to be so precise in our experiments, but nature is very stochastic—it’s messy.”

Not only is it messy, it’s also changing quickly. So far, a decline in pollinators is not on the radar in India, but Olsson believes it’s coming.

In fact, Bangalore seems to be home to surprisingly few pollinators, and Olsson wonders whether its growing pollution is interfering with pollinators’ chemical sensing abilities. Her lab is now taking a systematic look at the physiology and behavior of bees from different areas of Bangalore that are more and less polluted. Regardless of the species, there’s a lot to learn from how insects make decisions in nature, Olsson says—especially since human activities that drive pollution and climate change might be affecting the cues they rely on.

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