Flight of the Dragonfly Fabricating a playground for this precision hunter may provide the access scientists need to understand its neural circuitry.

FOR MANY ANIMALS, HUNTING CAN SEEM EFFORTLESS. Frogs flick their tongues to catch flies. Whales swim with their mouths open to strain plankton from the sea.

But no matter how straightforward an animal's technique seems, behind each attempt to capture prey whirs an intricate choreography of sensory input, neuronal firing, and muscle response that scientists do not fully understand.

Curious to know more, Anthony Leonardo, a group leader at HHMI's Janelia Farm Research Campus who studies the neural basis of animal behavior, decided to focus on dragonflies, which hunt with incredible precision, rarely missing their prey. Using an advanced video camera, he has been able to capture the insects in action, shooting 1,000 frames per second.

Played back at a speed the human eye can follow, a clip shows a perched dragonfly turning its head as it tracks a fruit fly. With coordinated strokes of its four gossamer wings, the insect lifts off and adjusts its route to intercept its prey. The dragonfly then glides, its hairy legs coming together to create a basket to imprison the fly before devouring it midair.

More important than their aerial grace, dragonflies are large and strong enough to carry a miniature, wireless system that will allow Leonardo to record their neurons firing in real time as they pursue their prey.

But first, he had to design and build an indoor "flight arena" that would encourage dragonflies to behave almost as they would in a natural setting.

"We don't want to reproduce the outside world—there's too much complexity. We want it to be just complex enough so the dragonflies act normally," he says.

One of Leonardo's collaborators, Rob Olberg of Union College in Schenectady, New York, helped with the design. Olberg, who is a visiting scientist at Janelia Farm through this summer, has already identified 16 key neurons that deliver information to the muscles involved in flight and prey capture. These neurons are believed to tell the dragonfly's wings the location of the fruit fly for an accurate capture.

But these findings were based largely on studying dragonflies held in place by miniature restraints. Olberg says his subjects are no doubt more concerned about escaping than about catching a meal. "The nervous system probably works a whole lot differently when the dragonfly is actually flying," he says.

With Leonardo's flight arena, a virtual meadow, understanding that difference might now be possible. Dragonflies are finicky creatures: they require far more space than the typical lab allows, special lighting that mimics the sun's ultraviolet spectrum, and visual cues to orient themselves.

The flight arena fully occupies a basement room about 14 feet wide, 18 feet long, and 15 feet high. In the beginning, it had white walls, a white ceiling, and a white floor. Put a couple of dragonflies in it, and they wouldn't budge; they just sat still on the bare floor. Being visual animals—they have two compound eyes, made of thousands of lenses, plus three simple eyes—they had no frame of reference, nothing to give them clues as to where they were or where they should fly.

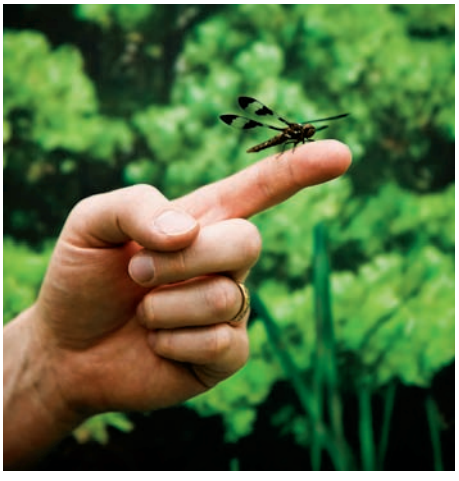
So, Leonardo and his technician, Elliot Imler, started adding high- and low-tech props from floor to ceiling. First they installed a carpet of artificial grass. Dragonflies zipped around the room, but without any other visual references, they flew in circles and into walls. To slow them down, the team put in "speed bumps"—vertical stripes on the walls, which later gave way to wall-to-wall posters of verdant forests and tulip gardens. To make it homier for the water lovers, they added a shallow pond and decorated its edges with plastic flowers and cattails, which serve as perches. Aimed at two of the perches are high-speed video cameras, one per perch.

Mindful of the insects' internal clocks, they re-created dawn and dusk with an array of lights programmed to brighten and dim, from east to west. A humidifier maintains constant moisture and the temperature hovers at 80 degrees; heat lamps directed at flower perches provide the additional warmth that dragonflies prefer.

To prompt the dragonflies to hunt, Leonardo and Imler suspended small plastic trays carrying banana bits crawling with fruit flies. The trays buzz regularly to startle the flies off their feast so the dragonflies can see and pursue them.

What keeps the arena softly humming with a steady stream of four to five dragonflies at a time is the lab's vivarium, where about 10 different species of dragonflies are raised from nymphs netted from Janelia's outdoor pond.

After several months of fine tuning, about half the dragonflies released in the room appeared to behave as if outdoors. Of those, 80 to 90 percent of one particular species, *Libellula lydia*, acted normally—that is, flying and hunting in the room for at least a couple



Anthony Leonardo's indoor flight arena has all the elements that allow dragonflies to thrive: grass, water, food, colorful gardens, daily light cycles, and controlled heat and humidity. To get his research subjects, Leonardo dons boots and a net and catches nymphs from the outdoor pond at HHMI's Janelia Farm Research Campus. So far, he's collected and raised 10 species of dragonfly.

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of days. This fraction is large enough to satisfy Leonardo that he's figured out an effective, basic formula for producing this complex behavior in an experimentally controlled setting.

Now, he is working with engineer Reid Harrison at the University of Utah on a wireless, electronic "backpack" for his tiny subjects. The pack, which will be glued to the belly of the dragonfly, will carry a mini-telemetry system. It will connect to electrodes inserted into the dragonfly's body. The electrodes will detect signals from the neurons Olberg identified, and a transmitter will send the data to a remote computer while an array of high-speed cameras simultaneously measures the dragonflies' flight path.

Together, the videos and the data from neuronal signals—and eventually muscle contractions—may one day yield a complete picture of how dragonflies' neural circuitry makes them such enviable hunters. ■ –CHRISTINE SUH

WEB EXTRA: Visit the *Bulletin* online to see more photos and hear Leonardo talk about the dragonfly arena.