How to Control an Army of Zombies

By CARL ZIMMER

In the rain forests of Costa Rica lives *Anelosimus octavius*, a species of spider that sometimes displays a strange and ghoulish habit.

From time to time these spiders abandon their own webs and build radically different ones, a home not for the spider but for a parasitic wasp that has been living inside it. Then the spider dies — a zombie architect, its brain hijacked by its parasitic invader — and out of its body crawls the wasp’s larva, which has been growing inside it all this time.

The current issue of the prestigious Journal of Experimental Biology is entirely dedicated to such examples of zombies in nature. They are far from rare. Viruses, fungi, protozoans, wasps, tapeworms and a vast number of other parasites can control the brains of their hosts and get them to do their bidding. But only recently have scientists started to work out the sophisticated biochemistry that the parasites use.

“The knowledge that parasites can manipulate their hosts is old. The new part is how they do it,” said Shelley Adamo of Dalhousie University in Nova Scotia, a co-editor of the new issue. “The last 5 to 10 years have really been exciting.”

In the case of the Costa Rican spider, the new web is splendidly suited to its wasp invader. Unlike the spider’s normal web, mostly a tangle of threads, this one has a platform topped by a thick sheet that protects it from the rain. The wasp larva crawls to the edge of the platform and spins a cocoon that hangs down through an opening that the spider has kindly provided for the parasite.

To manipulate the spiders, the wasp must have genes that produce proteins that alter spider behavior, and in some species, scientists are now pinpointing this type of gene. Such is the case with the baculovirus, a virus sprinkled liberally on leaves in forests and gardens. (The cabbage in a serving of coleslaw carries 100 million baculoviruses.)

Human diners need not worry, because the virus is harmful only to caterpillars of insect species, like gypsy moths. When a caterpillar bites a baculovirus-laden leaf, the parasite invades its cells and begins to replicate, sending the command “climb high.” The hosts end up high in trees, which has earned this infection the name treetop disease. The bodies of the caterpillars then dissolve, releasing a rain of viruses on unsuspecting hosts below.

David P. Hughes of Penn State University and his colleagues have found that a single gene, known as egt, is responsible for driving the caterpillars up trees. The gene encodes an enzyme. When the enzyme is released inside the caterpillar, it destroys a hormone that signals a caterpillar to stop feeding and molt.

Dr. Hughes suspects that the virus goads the caterpillar into a feeding frenzy. Normally, gypsy moth caterpillars come out at night to feed and then return to crevices near the bottom of trees to hide from predators. The zombie caterpillars, on the other hand, cannot stop searching for food.

“The infected individuals are out there, just eating and eating,” Dr. Hughes said. “They’re stuck in a loop.”

Other parasites manipulate their hosts by altering the neurotransmitters in their brains. This kind of psychopharmacology is how thorny-headed worms send their hosts to their doom.
Their host is a shrimplike crustacean called a gammarid. Gammarids, which live in ponds, typically respond to disturbances by diving down into the mud. An infected gammarid, by contrast, races up to the surface of the pond. It then scoots across the water until it finds a stem, a rock or some other object it can cling to.

The gammarid’s odd swimming behavior allows the parasite to take the next step in its life cycle. Unlike baculoviruses, which go from caterpillar to caterpillar, thorny-headed worms need to live in two species: a gammarid and then a bird. Hiding in the pond mud keeps a gammarid safe from predators. By forcing it to swim to the surface, the thorny-headed worm makes it an easy target.

Simone Helluy of Wellesley College studies this suicidal reversal. Her research indicates that the parasites manipulate the gammarid’s brain through its immune system.

The invader provokes a strong response from the gammarid’s immune cells, which unleash chemicals to kill the parasite. But the parasite fends off these attacks, and the host’s immune system instead produces an inflammation that infiltrates its own brain. There, it disrupts the brain’s chemistry — in particular, causing it to produce copious amounts of the neurotransmitter serotonin.

Serotonin influences how neurons transmit signals. Dr. Helluy proposes that the rush of serotonin triggered by the thorny-headed worms corrupts the signals traveling from the eyes to the brain. Normally, an escape reflex causes the gammarid to be attracted to the darkness at the bottom of its pond. Thorny-headed worms may cause their host to perceive sunlight as darkness, and thus swim up instead of down.

Whether humans are susceptible to this sort of zombie invasion is less clear. It is challenging enough to figure out how parasites manipulate invertebrates, which have a few hundred thousand neurons in their nervous systems. Vertebrates, including humans, have millions or billions of neurons, and so scientists have made fewer advances in studying their zombification.

Most of the research on vertebrate zombies has been carried on a single-celled parasite, Toxoplasma gondii. Like thorny-headed worms, it moves between predators and their prey. Toxoplasma reproduces in the guts of cats, which shed it in their feces.

Mammals and birds can pick up the parasite, which invade their brain cells and form cysts. When cats eat these infected animals, Toxoplasma completes its cycle. Scientists have found that Toxoplasma-infected rats lose their fear of cat odor — potentially making them easier prey to catch.

Glenn McConkey of the University of Leeds and his colleagues have found a possible explanation for how Toxoplasma wreaks this change. It produces an enzyme that speeds the production of the neurotransmitter dopamine, which influences mammals’ motivation and how they value rewards. Adding extra dopamine might make Toxoplasma’s hosts more curious and less fearful.

But Ajai Vyas of Nanyang Technological University in Singapore has found evidence that Toxoplasma simultaneously manipulates its hosts in other ways. Infected male rats, he found, make extra testosterone. This change makes the males more attractive to females, and when they mate the males spread the parasite to females.

By causing male rats to make more testosterone, Toxoplasma may do more than spread itself to other rats. Testosterone also tamps down fear. The infected rats may thus become even less concerned when they pick up the scent of a cat.

This research could potentially provide important clues about human behavior. In the case of Toxoplasma, for example, humans can become hosts if they handle contaminated cat litter or eat parasite-laden meat.
Some studies have linked Toxoplasma infection with subtle changes in personality, as well as with a higher risk of schizophrenia.

Dr. Adamo, the co-editor of the journal’s new issue, thinks this new science of “neuroparasitology” can offer inspiration to pharmaceutical companies that are struggling to find effective drugs for mental disorders. “A number of the big companies have given up on their neuroscience labs,” she said. “Maybe the parasites can teach us something.”

She points out that the way parasites manipulate brains is profoundly different from drugs like Prozac. “The way that a parasite goes about changing behavior is not the way a neurobiologist would do it,” she said.

A typical drug focuses on just one type of molecule in the brain. Parasites, on the other hand, often launch a much broader attack that still manages to cause a specific change in their host. “Perhaps tweaking several systems simultaneously might give better results than trying to hit one particular system with a sledgehammer,” Dr. Adamo said.

But she added that she and other parasitologists barely understand those zombifying tweaks. “All we know now,” she said, “is they have their own ways.”

Flesch-Kincaid: 10.2

Question Samples:

WHAT is the “strange and ghoulish habit” of Anelosimus octavius, a spider species that lives in Costa Rica?
WHAT examples in this article about “zombies in nature” are most vivid and interesting to you?
WHO has just learned, in the last 5 to 10 years, about how parasites manipulate and control their zombie hosts?
WHERE does a caterpillar end up after it bites a baculovirus-laden leaf?
HOW do thorny-headed worms send their hosts to their doom?
WHY is it difficult for scientists to figure out if humans are susceptible to this sort of zombie invasion?
WHEN can humans become hosts for Toxoplasma?