What Is It Like to Be a Bee?

Bees display a remarkable range of talents—abilities that in a mammal such as a dog we would associate with consciousness BY CHRISTOF KOCH

WE TAKE THE MAGICAL GIFT of consciousness for granted. From the time I awaken until I fall into a deep, dreamless sleep, I am flooded with conscious sensations. And contrary to assertions made by philosophers, novelists and other literati, by and large this stream of consciousness does not relate to quiet self-reflection and introspective thoughts. No, most of it is filled with raw sensations.

Two weeks ago a friend and I climbed a sea cliff above the Pacific surf at Malibu, Calif. When I am on the sharp end of the rope, my inner critic—that voice in my head reminding me of deadlines, worries and my inadequacies—is gone, is silent. My mind is all out there—conscious of the exact orientation, shape and texture of the rock, looking for tiny indentations where I can get purchase for my fingers and toes, always aware of how high I am above the last bolt. One moment I am exquisitely aware of my feet on all too smooth rock, reaching upward with my left hand for a handhold. The next I am airborne, my right hand bloody, my right rib cage aching. After catching my breath and shouting to my anxious belayer that I'm okay, I am filled with adrenaline for having survived yet another fall, can't contain my enthusiasm, and scream.

Today only the bruised rib remains as a testament to how much of the stream of consciousness is pure sensation. Whether you are weaving on a motorbike through flowing traffic, running in the mountains, dancing to fast rock and roll, reading an engaging book, making love or debating with your friend, your eyes, ears, skin and body sensors paint an engrossing picture of the outside, including your own body, onto your mind's canvas.

Animal Consciousness?

I suspect this feeling is not that dissimilar to the way animals consciously experience their world. Except perhaps for the great apes and a few other privileged big-brained animals, most species do not posses the highly developed sense of self, the ability to reflect on oneself, that people have. Most biologists and pet owners are willing to grant consciousness to cats, dogs and other mammals. Yet our intuitions fail us completely when we consider fish and birds, let alone invertebrates such as squid, flies or worms. Do they experience the sights and sounds, the pains and pleasures, of life? Surely they can't be conscious—they look too different from us, too alien.

A honeybee hovers in front of a flower with her antennae pointing forward.

Insects, in particular, were long thought to be simple, reflexive creatures with hardwired instinctual behaviors. No more. Consider the amazing capabilities of the honeybee, *Apis mellifera*.

Martin Giurfa of the University of Toulouse in France and Mandyam Srinivasan and Shaowu Zhang, both at the Australian National University in Canberra, trained free-flying bees, using sugar water as a reward, in a variety of complex learning tasks. The neuroethologists taught the bees to fly in and out of tall cylinders with one entryway and two exit holes. Each bee had to choose one of two exits to leave the cylinder and to continue her flight. (In bee colonies, males are a small minority and do only one thing—and that only during the virginal flight of the colony's queen.)

These cylinders were staggered into mazes with multiple levels of "Y" branch points that the bees encountered before reaching the desired feeder station. In one set of experiments, the scientists trained bees to track a trail of colored marks, as in a scavenger hunt. The bees could then follow—more or less—the same strategy in a completely unfamiliar maze. Amazingly enough, bees can use color in an abstract manner, turning right, for instance, when the branch point is colored blue and left when it is colored green. Individual animals developed quite sophisticated strategies, such as the right-turn rule, that always led to the goal, though not necessarily by the shortest route.

In humans, the short-term storage of symbolic information—as when you enter an acquaintance's phone number into your iPhone's memory—is associated with conscious processing. Can bees remember task-relevant information? The gold standard for evaluating working

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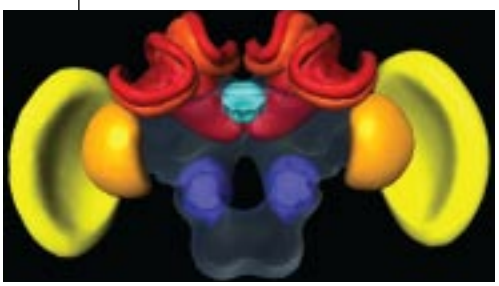
memory is the delayed matching-to-sample (DMTS) paradigm. The subject looks at a picture for a few seconds. The test image then disappears for five or 10 seconds. Subsequently, two pictures are shown next to each other, and the animal has to choose, by pushing a lever or moving its eyes, which of the two images was the test picture. This test can be carried out correctly only if the animal remembers the image. A more complex version, the delayed nonmatching-to-sample (DNMTS) task, requires one additional processing step: choosing the opposite image from the one previously shown.

Although bees can't be expected to push levers, they can be trained to take either the left or the right exit inside a cylinder modified for the DMTS test. A color disk serves as a cue at the entrance of the maze, so that the bee sees it before entering. Once within the maze, the bee has to choose the arm displaying the color that matches (DMTS) or differs from (DNMTS) the color at the entrance. Bees perform both tasks well. They even generalize to a situation they have never previously encountered. That is, once they've been trained with colors, they "get it" and can now follow a trail of vertical stripes if a disk with vertical gratings is left at the entrance of the maze. These experiments tell us that bees have learned an abstract relation (sameness in DMTS, difference in DNMTS) irrespective of the physical nature of the stimuli. The generalization to novel stimuli can even occur from odors to colors.

Insect Intelligence

Although these experiments do not tell us that bees are conscious, they caution us that we have no principled reason at this point to reject this assertion. Bees are highly adaptive and sophisticated creatures with a bit fewer than one million neurons, which are interconnected in ways that are beyond our current understanding, jammed into less than one cubic millimeter of brain tissue. The neural density in the bee's brain is about 10 times higher than that in a mammalian cerebral cortex, which most of us take to be the pinnacle of evolution on this planet. In humans, widespread loss of cerebral cortex, as in the vegetative patient Terri Schiavo, leads to an irreversible loss of consciousness. That is not to say that a cerebral cortex is necessary for consciousness in creatures with a different evolutionary heritage.



A view of the honeybee brain from the back. The brain, including the prominent lobes that process visual information and that lie just below the compound eyes (*yellow*), is about two millimeters across.

Bees live in highly stratified yet flexible social organizations with group decision-making skills that rival academic, corporate or government committees in efficiency. In spring, when bees swarm, they choose a new hive that needs to satisfy many demands within a couple of days (consider that the next time you go house hunting). They communicate information about the location and quality of food sources using the waggle dance. Bees can fly several kilometers and return to their hive, a remarkable navigational performance. Their brains seem to have incorporated a map of their environment. And a scent blown into the hive can trigger a return to the site where the bee previously encountered this odor. This type of associative memory was famously described by French novelist Marcel Proust in *À la Recherche du Temps Perdu*.

Given all of this ability, why does almost everybody instinctively reject the idea that bees or other insects might be conscious? The trouble is that bees are so different from us and our ilk that our insights fail us. But just because they are small and live in colonies does not mean that they can't have subjective states, that they can't smell the fragrance of the golden nectar or experience the warm rays of the sun or maybe even have a primitive sense of self. I am not a mystic. I am not arguing for pan-psychism, for the notion that anything is conscious. Nor am I assuming that bees can reason or can reflect on their fate as animated cartoon bees.

What this dilemma highlights is that there is no accepted theory of consciousness, no principled theory that would tell us which systems, organic or artificial, are conscious and why. In the absence of such a theory, we must at the very least remain agnostic about consciousness in these creatures. So the next time a bee hovers above your breakfast toast, attracted by the sweet jam, gently shoo her away. For she might be a fellow sentient being, experiencing her brief interlude in the light, shoehorned between this moment and eternity. M

(Further Reading)

- **The Concepts of "Sameness" and "Difference" in an Insect.** Martin Giurfa, Shaowu Zhang, Arnim Jenett, Randolf Menzel and Mandyam V. Srinivasan in *Nature,* Vol. 410, pages 930–933; April 19, 2001.
- **Three-Dimensional Average-Shape Atlas of the Honeybee Brain and Its Applications.** Robert Brandt et al. in *Journal of Comparative Neurology,* Vol. 492, No. 1, pages 1–19; November 7, 2005.
- For resources on the neurobiology and behavior of the honeybee, see **www.neurobiologie.fu-berlin.de/menzel/menzel.html**

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