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Insect Neurobiology: How Small Brains Perform Complex Tasks

A new study finds that bumblebees, like primates, can perform simple tasks that rely on rapid visual assessment, but unlike primates, require longer views for complex tasks. This suggests a fundamental difference in the way bees process visual information.

Jamie Theobald

A usually unspoken assumption in neurobiology is that larger brains generate more complex behavior [1]. This roughly fits our intuition for snails and frogs and dolphins, and after all, large brains take time to grow and energy to use, they must be good for something. But many insects seem to defy this trend by using quite tiny brains to produce startlingly sophisticated behaviors [2]. How do they get so much performance out of so little hardware? By training bumblebees to distinguish visual targets, Nityananda *et al.* [3] show that in a discrimination task, when images vary only subtly, bees require increasingly long looks to choose targets correctly. This is in contrast to primates: we can capture and analyze even complex scenes with a brief glance [4]. It suggests bees use inherently different neural schemes to analyze complex scenes, processes that require continuous, active vision, but can accommodate a tiny brain with limited neural resources.

When it comes to small animals producing implausibly sophisticated behaviors, bees are among the worst offenders. With fewer than a million neurons, ∼0.001% the number in the human brain, they divide the labor of building, maintaining, and defending sometimes massive colonies [5], forage over novel terrains using both landmarks and celestial cues [6], then return home and efficiently communicate routes to nestmates [7]. Can we dismiss these natural behaviors as simply innate, and therefore unremarkable? Not exactly. In the lab, social bees have proven to be highly trainable, in part because a worker seeks resources for the entire hive, and so will continue to respond to food rewards even when she, personally, is sated. Under experimental conditions bees can learn arbitrary associations based on color, shape, pattern, or motion [8], solve hard optimization problems [9], and navigate through mazes [10]. Bees are just plain impressive.

So what tricks might they be using to wrest complex behavior from tiny brains? One possibility is that, as small flying animals, their brains have been selected for miniaturization. Much like computer CPUs have shrunk through the years, flying insects may have evolved structural and molecular adaptations to squeeze more processing into fewer neurons. But another possibility is that they use fundamentally different sorts of processing, algorithms that usually generate complex behavior, but optimized to run in small, specialized brains.

To address this question, Nityananda *et al.* [3] trained bumblebees to discriminate between increasingly complex visual cues. Bees entered a chamber with six perching sites, three with drops of a dissolved sucrose reward, and three with drops of dissolved quinine hemisulfate, which bees dislike. To locate the rewards, bees had to examine the images behind each perch. Choosing the correct images required either distinguishing simple features, such as the presence or absence of a diagonal bar, or more subtle ones, such as two similar colors or shapes (Figure 1).

Bees are well known for their proficiency at this sort of test, and a typical bee has little difficulty if images are simply displayed behind the perches. However, to investigate the cognitive processing that underlies their skill, the researchers ran trials in which they merely flashed the distinguishing visual cues, presenting them for 100 milliseconds or less. Bees had to attempt to locate sucrose drops with ever shorter presentations of the stimulus, as brief as 25 ms.

For primates, this generally wouldn't pose a problem. Humans can analyze images presented for a mere 20 ms [4,11], and use parallel processing [12] in such a way that important features seem to simply jump out of otherwise cluttered visual scenes. Bees, with flashes of only 25 ms, could similarly analyze simple visual targets, such as the presence of bars or disks of strongly contrasting colors, and find their sucrose rewards. But they required longer flashes of 50 or 100 ms before they could reliably distinguish between harder visual targets, such as bars of different orientation or disks of slightly contrasting colors. And they could only perform the most difficult task, distinguishing disk and spider-shaped targets, when the images were continuously on. In other words, bees require ever longer looks to determine more subtle distinctions between images.

This is not because bee vision is slow. Honey bees are capable of simple visual distinctions with

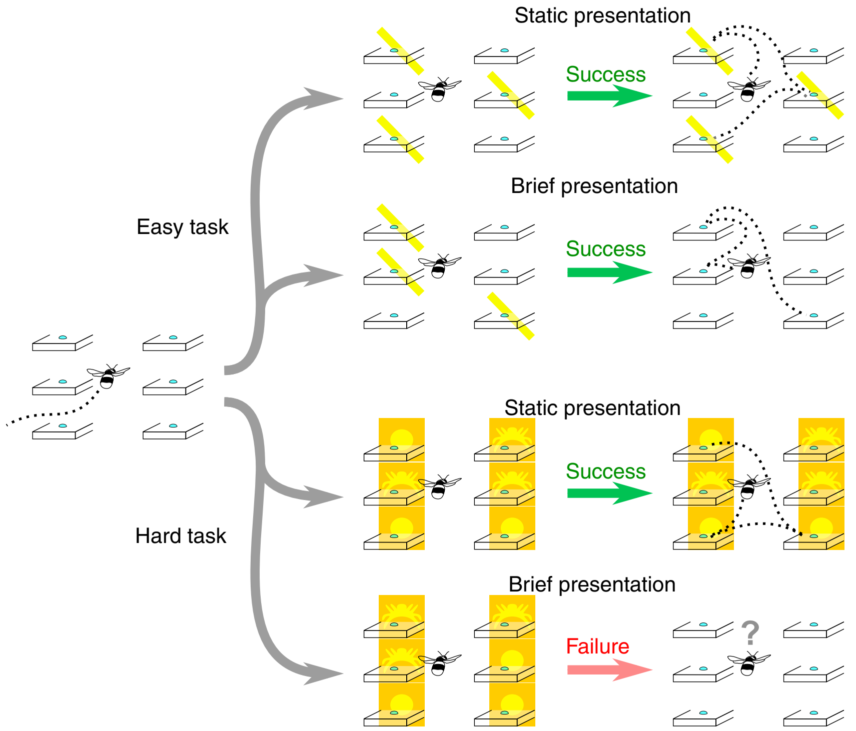

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Figure 1. Bumblebee attempting to locate rewards.

A bee faces six perches with droplets, three of sucrose solution, three of quinine hemisulfate. To find the sucrose, she must solve either a simple task, such as determine the presence of diagonal bars, or a harder task, such as distinguish the shape of a circle from a spider. Further, the images either persisted, or flashed for as briefly as 25 ms. Bees rely on increasingly long views to solve more difficult visual discriminations.

presentations as rapid as 2 ms [13]. And it is not because bees lack the ability to remember scenes when they are no longer present: both bees and wasps perform structured orientation flights, in which they turn to examine their nest from many different angles, in order to aid them in finding it when they return [14]. Rather, it may be that bees are forced to use active scanning, moving their heads and bodies, to analyze subtle differences between patterns. This contrasts in a fundamental way with primate vision, with its parallel analysis of low-level features to identify higher order structure. Bees can see images quickly, and store them in memory, but may be required to physically move their eyes around in order to explore the subtle spatial content. This is a limitation, but may better accommodate an insect brain. Serial image sampling may be an important strategy that allows bees to solve complex visual problems, even without the brain capacity to process a whole stored image.

Bees in the lab learn to perform many of the same tasks as primates, even humans, and are sometimes easier to train. They represent an unparalleled tool to study convergent evolution in the nervous system: vastly different brains working to solve similar problems. Primates pay a cost for larger brains [15,16], and studying the functional differences of the remarkable bee brain can help us understand why.

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Cell Division: The Prehistorichore?

The recent discovery of a novel kinetochore has important implications for our understanding of the evolution of chromosome segregation systems and also for the treatment of devastating parasitic diseases.

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A recent paper in *Cell* by Akiyoshi and Gull [1] reports that a class of single-celled eukaryotes possesses a kinetochore unlike any other, and this unique structure may provide insights into the possible nature of the prehistoric kinetochore. But the