Do fruit flies dream of electric bananas?
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It may be no bigger than a poppy seed, but some neuroscientists think the fruit fly's brain contains the rudiments of consciousness. Douglas Fox peers through this unlikely window on the human mind

A FRUIT fly hovers in mid-air. Its bulbous eyes capture a panoramic view of the world, but it ignores most of what it sees. Instead, it is captivated by one small thing: a bright green stripe that just zipped by. It's worth a closer look, worth landing on. The fly chases after it.

Or so it thinks. The fly is actually in a laboratory and suspended on a wire inside a miniature flight simulator. Surrounding the fly is a cylindrical LED screen, and travelling around that screen is a vertical stripe of green light. Each time the stripe comes into view, the fly tries to steer towards it. Sensors count the fly's wing beats, measure its orientation, and control the motion of the stripe accordingly. If the fly steers hard enough, it can halt the stripe and hold it steady in its view.

It's a neat gizmo, but watching it work I discover there's more to it than that. Inserted in the fly's brain is an electrode, and buzzing through that electrode, scrolling across a computer screen, are some curious brainwaves. Whenever the fly steers towards the stripe, these saw-tooth waves grow taller, and when the fix is lost, they shrink.

Ralph Greenspan, the researcher showing me this experiment, thinks these little waves are a very big deal. "The fly thinks that something important is happening to it," he says. "That stripe is what the fly considers to be a significant stimulus from its environment." In other words, the fly is paying attention.

That might not sound too impressive. Even a fruit fly needs to be able to focus on important stimuli - how else would it find food or avoid danger? But there's more to it than that. The brainwaves that Greenspan has found look uncannily like the ones you see in a human brain when it is paying attention.

This is a tantalising discovery. To neuroscientists, attention is a profoundly interesting and important phenomenon. We are constantly bombarded by information - smells, sounds, sights - yet we attend to only the slenderest sliver of the whole; the rest we tune out, just as you tune out the rumble of passing traffic as you read. Exactly how the brain achieves this feat is one of neuroscience's biggest questions, and for good reason:

attention is intimately associated with consciousness. What you pay attention to defines how you experience the world from moment to moment.

Many neuroscientists believe that if they can discover how the brain decides what to pay attention to, they will have taken the first step towards teasing out the neuronal basis of consciousness. And that's why finding human-like attention in a fly is so promising. Flies are much easier to work with than people - could studying their brains open a new window on the human mind?

I was eager to see how one studies a brain the size of a poppy seed, and what, if anything, the results say about the human mind. So I decided to visit Greenspan and his colleague Bruno van Swinderen at the Neurosciences Institute in San Diego, California.

It's little wonder that insects are generally considered to be little more than hard-wired, dim-witted automatons. A fruit fly brain contains just 250,000 neurons, compared with a human's 100 billion. Even the honeybee, considered the brainiest of insects, has only a million neurons. And on the surface, a fruit fly's brain looks nowhere near as complex as a mammal's.

Yet recent behavioural studies have caught insects doing seemingly un-insect-like things that hint at more complex brain functions. Sleep, for example, was thought to be the sole preserve of vertebrates, but in 1999 Greenspan's team found that fruit flies sleep every night. They also learn the way that Pavlov's dogs did: immerse a fly in peach odour and shock its foot, and it will avoid peaches. And just as humans possess separate short, medium and long-term memory, so do fruit flies: mutations have been discovered that selectively block each type, proving they exist in the first place. Flies also react to general anaesthetics in the same way as humans, losing equivalent brain functions at equivalent doses.

Honeybees can learn the abstract concepts "same" and "different" and apply them to novel situations. Researchers demonstrated this when training bees to navigate mazes, by teaching them to always choose passages marked with the same colour or smell they encountered at the maze entrance, regardless of the particular colour or odour used. They also did the reverse, training bees to choose passages marked differently from those at the maze opening. "We are not saying that insects are Einstein," says Martin Giurfa, a neuro-ethologist at the University of Toulouse (III), France, who was involved in the honeybee study. "In contexts relevant for their natural life they could be Einstein, but in other contexts they are absolutely stupid."

These behavioural studies have gone a long way towards dispelling the notion of insects as robotic dullards, but the brain circuits underlying these behaviours were considered off-limits because insect brains are so small. Not any more. Now that Greenspan and van Swinderen have found a way to prise open the fly's brain and eavesdrop on its internal dialogue, there are all sorts of possibilities.

It began during lunch one day as Greenspan and van Swinderen chatted with colleague Douglas Nitz, a mouse neuroscientist. For a lark, they decided to try recording an EEG from a fly's brain. The first run was as garden-shed science as it gets: Nitz, who is blessed with bomb-squad hands, held the electrode steady in the fly's brain with his fingers. Unbelievably, it worked, and soon they had recorded the first EEG of fruit fly sleep: its brain quietened down and produced fewer spikes, like a mammal brainstem during non-REM sleep. After sleep, it was only natural for the team to look for attention in the fly. After all, they are opposite ends of the same spectrum.

In a closet-sized lab, I wheel about on a stool, careful not to bump van Swinderen, who is bent over a microscope, wiring up today's fly. To me it looks crude - the electrode seems almost the size of the fly's head - but it's actually pretty exact. Adjusting the knobs of a micromanipulator, van Swinderen places the electrode exactly where he wants it - between the brain's mushroom bodies. If you are going to see the signature of attention anywhere in a fly's brain, this is where you'd expect to find it. The mushroom bodies receive multiple sensory inputs, including smell and vision, and also recall memories. And sensory information plus memory are the building blocks of attention: comparing a stimulus with past experience to determine whether it's worth paying attention to, on account of it being good, bad or new.

Van Swinderen hits a key and the show begins. A jagged Alps of brainwaves dances across the computer screen, and each time the stripe whizzes past the fly's field of vision, those waves change slightly. After a few runs van Swinderen feeds the waves through a computer analysis and the picture becomes clear. He is capturing a bundle of superimposed frequencies, but one set - between 20 and 30 hertz - grow stronger when the stripe passes. Greenspan and van Swinderen reckons these are an unmistakable signal of what they call "salience" - the fly equivalent of attention. They prefer "salience" to "attention" because they don't want to suggest, even obliquely, that flies are conscious.

There are several reasons for believing they are right. In the flight simulator, they see the 20 to 30 hertz signal whenever the fly is steering towards a stripe. The first time a stripe comes into view, the signal increases, but with each new pass the increase shrinks slightly as the fly gradually loses interest - until a new stripe appears. What's more, the signal increases when you enhance the importance of that stripe for the fly - by simultaneously puffing the fly with banana odour, which it likes, or heating it with a lamp, which it doesn't. And if you show the fly the stripe alone, having previously shown it at the same time as heating the fly, the signal is still elevated: the fly associates that stripe with something bad, so watches it even more intently. It all suggests that the 20 to 30 hertz signal encompasses not just vision, but other senses too - that it reflects some overall assessment of whether something is worth keeping an eye on or can be safely ignored. What van Swinderen finds most telling is that when the fly watches the stripe, it ignores everything else. "Suppression is the hallmark of attention," he says.

There is another telltale sign. The electrode records from three different regions of the brain. Normally, the electrical chatterings of these regions are as different as the languages spoken in the Tower of Babel. But show the fly a stripe and they suddenly fall into sync at 20 to 30 hertz, rising and falling in unison like a crowd doing a Mexican wave. This is called synchrony and it is exactly what you see in a mouse or human brain when it pays attention to something. Synchrony is attention defined: all eyes focused on one stimulus, one stripe, one wave - and everything else is ignored.

Synchrony is also interesting because neurologically it resembles what consciousness probably is. Unlike, say, olfaction or face recognition, which occur in specific brain regions, no one expects to find a localised "consciousness centre". Instead, neuroscientists expect consciousness to be about how brain regions are interconnected: the brain's various regions, even distant ones, will be intimately wired together, equipped for the continuous 10,000-way conference call that is consciousness.

So for many reasons attention and synchrony in a fly are very interesting, but what can you do with them? Greenspan has some ideas. "The salience response in flies looks like a very simplified version of the attentiveness response seen in humans," he says. And that's exciting, because it suggests that maybe this would be a model system for dissecting human attention.

With this model system, researchers could finally combine the ability to record complex brain activity - traditionally only done in mammals - with the sophisticated genetic manipulation that is possible only in fruit flies. They could screen hundreds of mutations to find genes involved in attention, and then knock out the same genes in cells in the fly brain - even in single neurons. In this way, they could eventually map the entire brain circuits that control attention in flies. That would be a step towards doing the same in mammals. And once you have identified mammalian attention circuits, you would - perhaps - learn something about human consciousness.

For now, though, it's what's going on in fly brains that is getting all the attention. When the researchers presented their results at the International Congress of Genetics in Melbourne, Australia, last July, newspapers trumpeted the earth-shattering news: "Fruit flies are conscious". Those stories were overblown, yet there was something to them.

"With consciousness there's the whole human baggage which is not worth talking about in flies," says van Swinderen. "Philosophers waste a lot of time thinking about such things. But a phenomenon like attention can be completely understood - how an animal assigns salience to objects based on experience, and how its internal representations of the world match the external world."

To him, it is significant that if you are showing a fly a rotating stripe, and then add a second stripe, the salience signal suddenly switches to the new stripe. The fly's attention shifts to something new. This suggests that the fly has something akin to a stream of consciousness. I put this to van Swinderen and he sets me straight: not a stream of consciousness, a stream of attention.

What's the difference? "Attention builds consciousness," he explains. "If you couple attention to a load of memory, then maybe you can be conscious after a lot of learning through a long life." A fruit fly, whose entire being is shoehorned into 250,000 neurons and 30 days of life, never gets there and never could. But it dabbles in the process, and van Swinderen hopes to study it.

He envisages building a virtual maze for the flies to explore. First he would present the fly with two visual stimuli to see which evokes a larger salience response. Then, depending which it chooses, he would present it with two more stimuli, and so on. The fly could navigate this maze for hours.

"That's what I'm really excited about: having the fly tell me what's important to it," he says. "If you let it choose the images, you can learn a lot about attention and learning."

Van Swinderen thinks he could use this experimental design to identify how the fly decides if something is salient. Show the fly two visual cues and see which it pays more attention to. Then show it two variations of the one it has chosen. Repeat this over many rounds and you end up optimising the salience of the cue. Using this system you would discover to what degree those salience criteria are hard-wired in all flies, as opposed to being shaped by each fly's experiences.

Or if the fly learned to avoid something unpleasant, van Swinderen could determine how far back the association went. For example, if a square leads to a triangle leads to a circle leads to heat, could flies learn to avoid the square, or would they recognise the threat only after seeing the circle? Such experiments would be useful because they look at the fly's use of memory to judge salience, and this could be a first step towards asking whether they merely access their memories, or can somehow pay attention to them.

The salience signal could advance dozens of other research areas, too. Fruit flies are great for identifying genes involved in brain functions such as learning and memory. But researchers must often rely on vague behavioural measurements, such as courtship, to assess what those genes do. Such assessments are notoriously ambiguous. A mutation that garbles maze navigation, for example, might do so in dozens of different ways - by disrupting memory, eyesight or even flight muscles. Maze navigation is the sum of all these things so a behavioural change might not reveal the underlying cause. But the salience signal allows researchers to look directly at the brain, without having to guess.

"It's a tremendous tool," says Howard Nash, who studies fruit fly anaesthesia at the National Institutes of Health in Bethesda, Maryland. "It will allow us to look at things which a year ago I would have said we'd never learn from a fly."

For me it explains a lot, too, not least why flies are so adept at disappearing as soon as you arrive with a fly swatter. So next time you pit your wits against an insect and lose, maybe you shouldn't feel so bad. Its mind may be elementary and diminutive, yet it is not so different from your own.

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