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Diminishing returns in neuroscience

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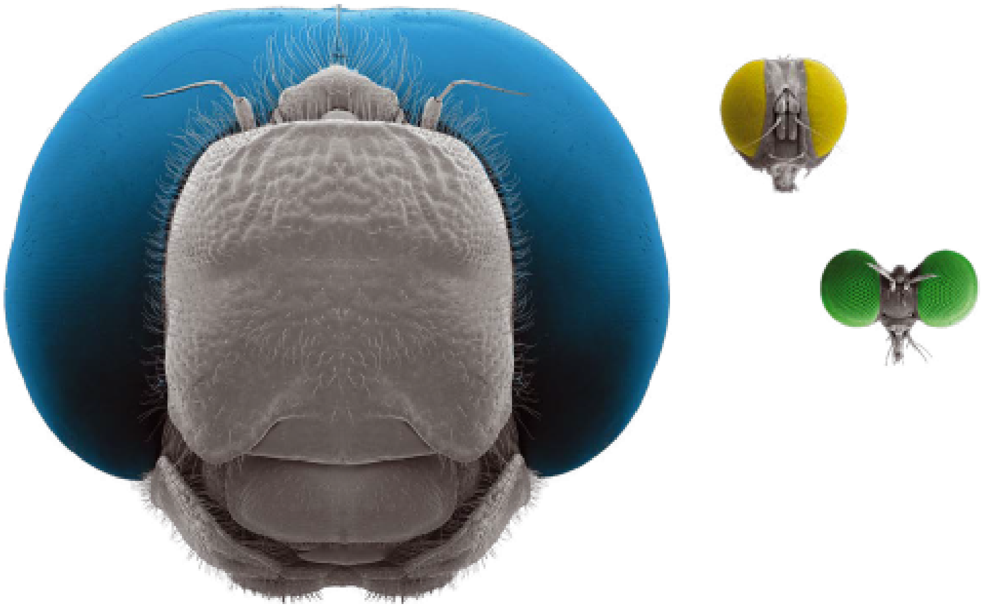

A dragonfly (blue) has a larger brain than a robber fly (green) or a killer fly (yellow), but what are the trade-offs?

Cambridge researchers are studying what makes a brain efficient and how that affects behaviour in insects – including in the aptly named killer fly.

As in economics, there is a law of diminishing returns in neuroscience – doubling the investment going in doesn't equal double the performance coming out. With a bigger brain comes more available resources that can be allocated to certain tasks, but everything has a cost, and evolution weighs the costs against the benefits in order to make the most efficient system.

"Larger brains are specialised for high performance, so there's a definite advantage to being bigger and better," says Professor Simon Laughlin of the Department of Zoology, whose research looks at the cellular costs associated with various neural tasks. "But since most animals actually have very small brains, there must also be advantages to being small." Indeed, there is strong selection pressure to have the minimum performance required in order to survive and it's not biologically necessary to be the best, only to be better than the nearest competitor.

So does size matter? Do small insects with relatively few neurons have the same capabilities as much larger animals? "When an animal is limited, is it because their neural system just can't cope? Or is it because they're actually optimised for their particular environment?" asks Dr Paloma Gonzalez-Bellido from Cambridge's Department of Physiology, Development and Neuroscience.

With funding from the US Air Force, Gonzalez-Bellido is studying the hunting behaviours of various flying insects – from tiny killer flies, slightly larger robber flies to large dragonflies – to determine how their visual systems influence their attack strategy, and what sorts of trade-offs they have to make in order to be successful.

Dragonflies are among the largest flying insects and hunt smaller insects such as mosquitoes while patrolling their territories. They have changed remarkably little in the 300 million years since they evolved – most likely because they are so well optimised for their particular environmental niche.

"Other researchers have found that dragonflies are capable of doing complex things like internally predicting what their body is going to do and compensating for that – for instance, if they're chasing a target and turn their wings, another signal will be sent to turn their head, so that the target stays in the same spot in their visual field," says Gonzalez-Bellido. "But are smaller animals, such as tiny flies, capable of achieving similarly complex and accurate feats?"

Gonzalez-Bellido also studies the killer fly, or Coenosia attenuata. These quick and ruthless flies are about four millimetres long, and will go after anything they think they can catch – picky eaters they are not. However, the decision to go after their next meal is not as simple as taking off after whatever tasty-looking morsels happen to fly by. As soon as a killer fly takes off after its potential prey, it exposes itself and runs the risk of becoming a meal for another killer fly.

To help these predacious and cannibalistic flies eat (and prevent them from being eaten), they need to fly fast and to see fast. Insects see at speeds much higher than most other animals, but even for insects, killer flies and dragonflies see incredibly fast, at rates as high as 360 hertz (Hz) – as a comparison, humans see at around 60 Hz.

"For prey animals, the most important thing is to get out of the way quickly – it doesn't matter whether they know exactly what's coming, just that it doesn't catch them," says Gonzalez-Bellido. "Predators need to be both fast and accurate in their movements if they're going to be successful – but for very small predators such as insects, there are trade-offs that need to be made."

By making the 'pixels' on their photoreceptors (the light-sensitive cells in the retina) as narrow as possible, killer flies trade sensitivity for resolution. In bright light, they see better than their similar-sized prey, the common fruit fly. However, the cap on sensitivity and resolution imposed upon killer flies by their tiny eyes means that they can only see and attack things that fly close by.

While dragonflies, with their larger eyes and better resolution, can take their time and use their brain power to calculate whether a prey is suitable for an attack, killer flies attack before they've had a chance to determine whether it's something they can actually catch, subdue or eat – or they risk missing their prey altogether. Once a killer fly gets relatively close to its potential prey, it has to decide whether to keep going or turn back – this is one of the trade-offs resulting from evolving such a tiny visual system.

In the early 2000s, Laughlin determined the energy efficiency of single neurons, by estimating the numbers of ATP molecules – the molecules that deliver energy in cells – used per bit of information coded. To do this he compared photoreceptors in various insects. Laughlin and his colleagues found that photoreceptors are like cars – the higher the performance, the more energy they require, and costs rise out of proportion with performance. "For any system, whether it's in a tiny insect or a large mammal, you don't want something which is over-engineered, because it's going to cost more," says Laughlin. "So what's the root of inefficiency, and how did nature evolve efficient nerve cells from the bottom up?"

Researchers in the Department of Engineering are taking the reverse approach to answer questions about how the brain works so efficiently by looking at systems from the top down. "If you reverse engineer an animal's behavioural strategy by asking how an animal would solve a task under specific constraints and then work out the optimal solution, you'll find it's often the case that animals are pretty close to optimal," says Dr Guillaume Hennequin, who looks at how neurons work together to produce behaviour.

Hennequin studies how brain circuits are wired in such a way that they become optimised for a task: how primates such as monkeys are able to estimate the direction of a moving object, for example. "How brain circuits generate optimal interpretations of ambiguous information received from imperfect sensors is still not known," he says. "Coping with uncertainty is one of the core challenges that brains must confront."

Different animals come up with their own solutions. Both dragonflies and killer flies have systems that are optimal, but optimal in their own ways. It's beneficial for killer flies to be so small, since this gives them high manoeuvrability, enabling them to catch prey that turns at speed. Dragonflies are much bigger, and can do things that killer flies can't, but their size means they can't turn or stop on a dime, like a killer fly can.

"By answering some of the questions around efficiency in brain circuits, large or small, we may be able to understand fundamental principles about how brains work and how they evolved," says Laughlin.

Provided by University of Cambridge

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