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Research suggests fly brains make predictions, possibly using universal design principles

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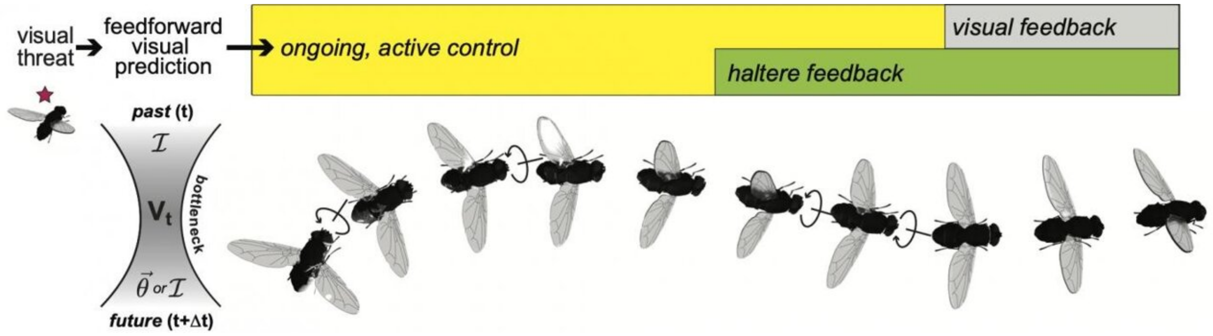

Flies make exceptionally fast escape maneuvers in response to visual threats (pink star). The behavior unfolds so rapidly that there is not time for vestibular (haltere) or visual feedback to control flight. Visual prediction that flows through the vertical sensing system's "information bottleneck" may help control flight in this open-loop interval. This information could flow directly to the wing steering muscles, as an instantiation of the so-called "control-loop" hypothesis. Credit: This image was created by authors S.E. Palmer and S. Wang, with 3D fly illustrations from D.A. Drummond.

Flies predict changes in their visual environment in order to execute evasive maneuvers, according to new research from the University of Chicago. This reliance on predictive information to guide behavior suggests that prediction may be a general feature of animal nervous systems in supporting quick behavioral changes. The study was published on May 20 in *PLOS Computational Biology*.

Animals use their sensory nervous systems to take in information about their environments and then carry out certain behaviors in response to what they detect. However, the nervous system takes time to process this sensory information, meaning that the environment can change by the time the previous information has been fully processed.

"This is really important in predator/prey interactions," said senior author Stephanie Palmer, Ph.D., Associate Professor of Organismal Biology and Anatomy at UChicago. "For a fly, everything is trying to eat you, and you want to avoid being eaten. However, the fly's environment is rapidly changing, and the neurons they have are laggy. We wanted to study how flies were able to execute quick evasive behaviors to avoid being eaten by predators when ongoing feedback from their sensory systems hasn't been processed."

To answer this question, the investigators took a highly interdisciplinary approach. "This is a project born out of this new era of open science sharing," Palmer said. "We were able to take the precise behavioral recordings made by another group and use them for a theoretical, computational neuroscience question: Does the fly's visual system make predictions using the initial detection of a threat that can span the lag time in processing of additional feedback as the fly starts its evasive behavior?"

Previous work from first author Siwei Wang, Ph.D., a postdoctoral researcher in Palmer's group, looked at a theoretical model of how encoding motion in the fly visual system might work. "I had an idea of how to extend these ideas to prediction, and this study allowed me to compare my model to real life behavioral data to test my theory," Wang said.

Using detailed diagrams of the connectivity between neurons in the fly visual system, the researchers made a simulation of the visual response as they fed in the previously recorded behavioral data set. "We compared what an optimal prediction would look like and what the fly's prediction looks like, and then we broke open the simulation to try to identify which parts were the most important for making these predictions," Palmer said.

The authors first identified that sensory data about the fly's visual world passes though an information bottleneck, where some of the sensory data is thrown out by the fly's brain because it simply does not have enough computing power to handle the amount of information it is taking in. However, the fly cannot indiscriminately discard visual information, because some of it might be useful for making predictions.

The authors identified structures called axonal gap junctions, which are physical channels connecting the neurons, that mediate an optimal form of this information bottleneck and are critical for both filtering out the unnecessary information and preserving the necessary information to make predictions.

The investigators further found that a subpopulation of these vertical motion sensory neurons that are involved in making predictions is unique in that it is also directly connected to the fly's flight steering neurons. This suggests that there is direct input from the neurons responsible for making predictions about the fly's environment to neurons that control the fly's behavior. This direct connection might explain how predictions that the fly is making are able to quickly influence its behavior.

Identification of these structures and the ability of the fly visual system to make predictions is likely to drive insight into how other animals' nervous systems make similar predictions.

"Cracking open the black box of how the fly does this has revealed what we think are universal design principles that the nervous systems of other animals probably also use," Palmer said. "We're interested in searching for another example of prediction-guiding behavior in another animal and asking if what we found in the fly really does apply broadly across species."

Ultimately, this kind of theoretical neuroscience may shed light on how our human brains function. "One of our greatest challenges as humans is understanding how everything inside our head works. Insights from work on flies can be generalizable and actually give us clues to how our brains operate," Palmer said.

Wang said the results could even have implications for understanding neurodegenerative diseases like Alzheimer's disease, where the brain loses the ability to make predictions. If the insights gained from these fly studies hold true in humans, it could help uncover new specific targets for therapeutic intervention. "We're still a long way from that, but this research in flies is setting the ground work to allow others to do that down the line," Wang said.

More information: Siwei Wang et al, Maximally efficient prediction in the early fly visual system may support evasive flight maneuvers, *PLOS Computational Biology* (2021). DOI: 10.1371/journal.pcbi.1008965

Provided by University of Chicago Medical Center

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