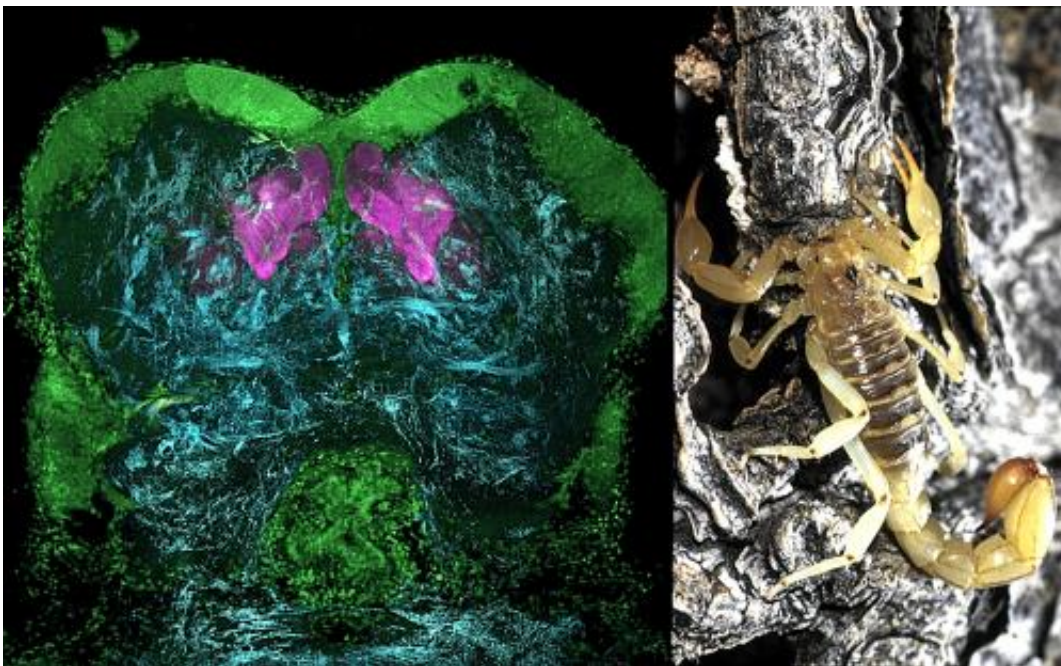


# Brain structures devoted to learning, memory highly conserved in animal kingdom, suggesting common evolutionary origin

December 18 2014

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Memory centers called mushroom bodies in the forebrain of a scorpion, revealed here by antibodies. Credit: Left: Gabriella Wolff; right: Chip Hedgecock

Whether you're cramming for an exam or just trying to remember where you put your car keys, learning and memory are critical functions that we constantly employ in daily life.

It turns out that the structure and function of brain centers responsible

for [learning and memory](#) in a wide range of invertebrate species may possibly share the same fundamental characteristics, according to a new study published in the journal *Current Biology* and performed by University of Arizona neuroscientists Nicholas Strausfeld, Regents' Professor in the Department of Neuroscience, part of the UA's School of Mind, Brain and Behavior, and Gabriella Wolff.

The brain centers in question are paired, lobed structures first discovered in insects and known as mushroom bodies. These centers occur in the forebrains of arthropods, as well as in marine worms and flatworms.

Because the commonalities between mushroom bodies in different species are so striking, there long has been a debate about whether these structures evolved independently or whether they derive from a common ancestor. Strausfeld's and Wolff's analysis revealed a ground pattern organization that is common to mushroom bodies in all of the investigated species, suggesting its inheritance from an ancient ancestor, possibly 600 million years in the past.

"This ground pattern of mushroom bodies is ubiquitous across a broad range of species," said Wolff, a graduate student in the Neuroscience Graduate Interdisciplinary Program. "If we wanted to emulate a learning and memory center in an artificial intelligence or a robot, this is where we would start."

Strausfeld and Wolff looked at both the neuroanatomy and chemical composition of mushroom bodies in numerous species belonging to two major groups of invertebrates: Ecdysozoa, which includes insects, crustaceans and other arthropods such as scorpions and horseshoe crabs; and Lophotrochozoa, which includes mollusks, flatworms and segmented worms.



Despite the distant evolutionary relationship shared by an American cockroach and a marine ragworm, their memory centers have the same organization. Credit: Gabriella Wolff, top and bottom left; Chip Hedgecock, top right; N. Strausfeld, bottom right

Using a variety of chemical staining techniques, Strausfeld and Wolff were able to study and compare the neuroanatomy of different species in great detail. Not only were the characteristics of individual mushroom body neurons the same across species, their organization among each other was the same as well. The researchers found that parallel bundles of neuronal fibers in the mushroom bodies in each species are arranged in similarly structured, orthogonal networks typical of learning circuits.

Next, the team analyzed protein expression in mushroom bodies. It found that the abundance of three proteins—called DC0, Leo and CaMKII—was conserved in the mushroom bodies across these invertebrate groups. Previous behavioral studies have shown that these proteins are necessary for learning and memory, and their genetic sequences are almost exactly the same in fruit flies and rats.

Remarkably, these same proteins also are thought to be critical for learning and memory in humans, and are implicated in neurological disorders such as Alzheimer's disease, Down syndrome and Angelman syndrome.

After the study on invertebrate brains, Strausfeld and Wolff will embark on investigating vertebrates such as rats, birds, reptiles, amphibians and fish.

"We hope to find out whether or not a similar ground pattern of organization occurs across the vertebrates, and whether that pattern also includes these highly abundant proteins," Strausfeld said. "The candidate that might possess this ground pattern is the hippocampus, which is crucial for memory of place, among other things.

"People may recoil at the idea that their brains share commonalities with arthropods and other invertebrates. The fact of the matter is that the organizational principles are the same. This should be of great interest to biomedical researchers."

According to Strausfeld, confirmation of this shared ground pattern in the vertebrate hippocampus would suggest that it originated from a very ancient [common ancestor](#) likely to have lived about 600 million years ago just before the Cambrian explosion, a relatively short period when most major animal phyla emerged.

This means it is possible that [brain](#) structures responsible for learning and memory in nearly all animals that possess them—including humans, but with the possible exception of mollusks—may have originated from one ancestor and have since undergone divergent evolution into centers of various complexity.

Next time you feel like swatting a fly, you might want to think twice.

"The correspondence across disparate groups of animals is extraordinary," Strausfeld said. "It's almost too good to be true."

**More information:** The abstract of the paper, "Genealogical Correspondence of Mushroom Bodies across Invertebrate Phyla," is available online at [www.cell.com/current-biology/a ... 0960-9822\(14\)01358-X](http://www.cell.com/current-biology/a ... 0960-9822(14)01358-X)

Provided by University of Arizona

Citation: Brain structures devoted to learning, memory highly conserved in animal kingdom, suggesting common evolutionary origin (2014, December 18) retrieved 10 April 2024 from <https://phys.org/news/2014-12-brain-devoted-memory-highly-animal.html>

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