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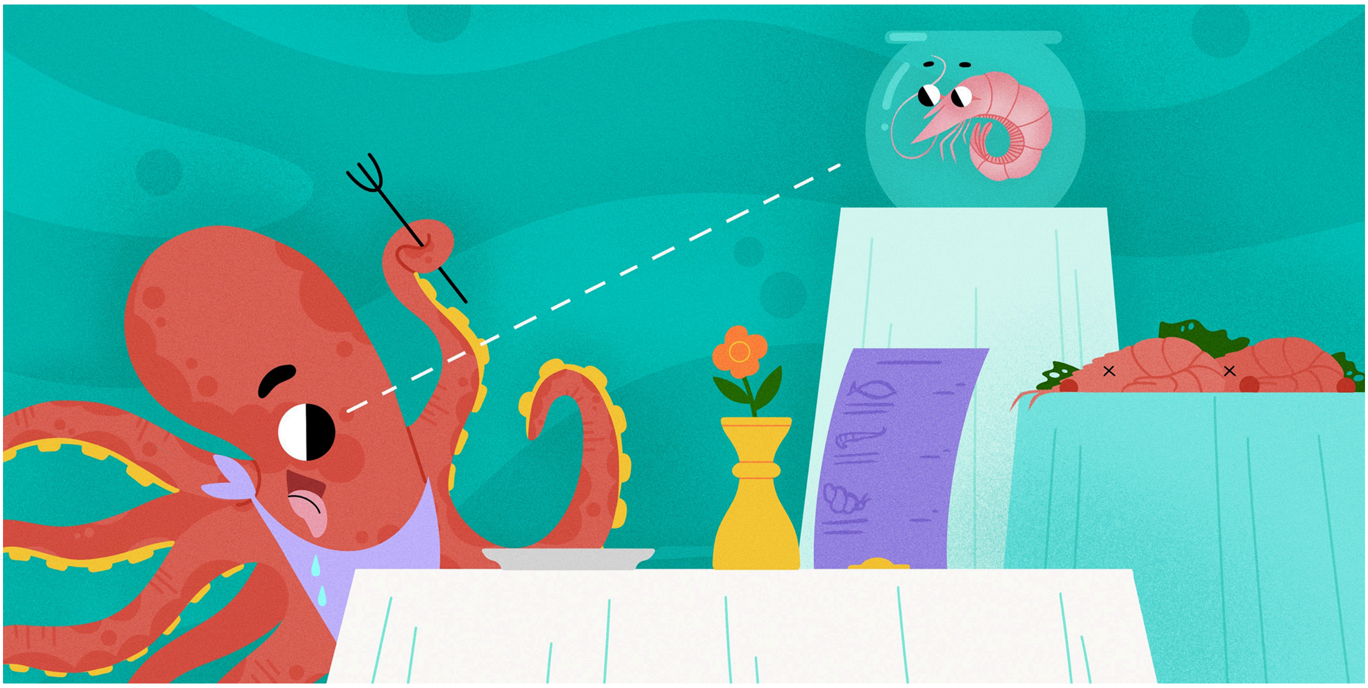

HOW INTELLIGENT IS AN OCTOPUS OR A CUTTLEFISH? EVEN SMARTER THAN YOU MIGHT THINK!

***Alexandra Schnell*[1], *Lynnie Fein-Schaffer*[2], *Jonathan B. Fritz*[2,3*] and *Nicola Clayton*[1]**

[1] *Department of Psychology, Cambridge University, Cambridge, United Kingdom*
[2] *National Science Foundation, Alexandria, VA, United States*
[3] *Center for Neural Science, New York University, New York, NY, United States*

YOUNG REVIEWERS:


ALICE
AGE: 11


CLAUDIO
AGE: 15

How smart is an octopus? Although we often associate intelligence with animals like dolphins, apes, elephants, parrots, and members of the crow family (jays and ravens), recent studies have revealed that octopuses and cuttlefish are also intelligent. These cephalopods have the largest brains amongst invertebrates, but their brains are completely different from our own human brains. Unlike many animals, an octopus grows up and learns on its own, without any instruction from its parents. An octopus quickly learns how to hide and camouflage itself to avoid predators. Octopuses have also been shown to use tools and sometimes they like to play. Cuttlefish, like their octopus cousins, are extremely intelligent. They are dazzling masters of camouflage, and have an excellent ability to remember past experiences, which helps guide their future behavior and decision-making. These clever cephalopods are revealing new insights that are helping scientists to understand how intelligence evolved.

WHAT IS A CEPHALOPOD?

Cephalopods (from the Greek word *kephalopodes*, literally meaning "head-feet") are a class of marine molluscs including the **nautilus**, **squid**, **octopus**, and **cuttlefish**. These animals have prominent heads and nimble, dexterous arms or tentacles modified from the ancient molluscan foot. Cephalopods are invertebrates (animals without backbones) and they diverged from vertebrates half a billion years ago (Figure 1). Over millions of years, cephalopods have evolved a unique and amazing form of intelligence, which scientists are just beginning to understand and appreciate. Cephalopods display their intelligence in many creative ways, including camouflage.

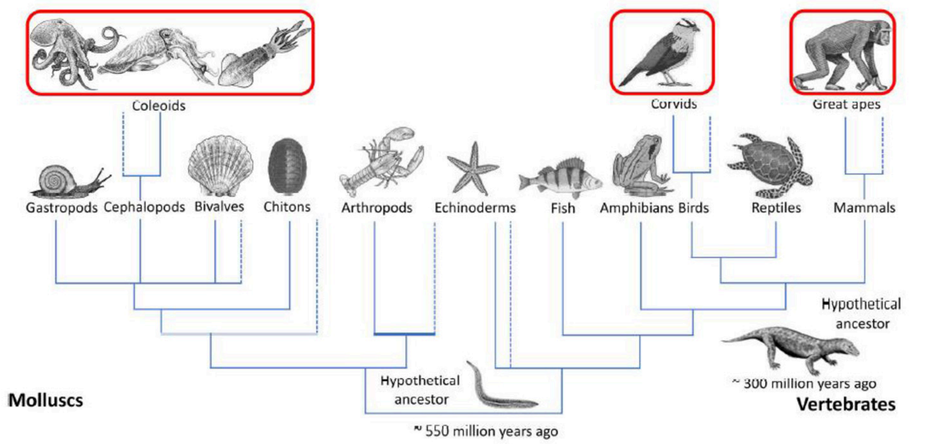

Figure 1

HOW DO CEPHALOPODS USE CAMOUFLAGE?

What if you could hide in plain sight, just by matching the exact fabric pattern of the Persian rug on your floor, the furniture in your room, or the floral wallpaper behind you? Guess what? Cephalopods have this incredible ability! Blending-in is a brilliant way of becoming invisible and avoiding predators. It's like a magic trick (that can also save the life of the cephalopod magician from a hungry shark!). Using three types of skin cells (called **chromatophores, iridophores, and leucophores**) on their body, an octopus can change color in the blink of an eye. Not only can octopuses and cuttlefish change skin color, but they also have special cells called **papillae** on their skin, that allows them to change their body surface to match the 3-D background texture of a rocky coral reef or bumpy seaweed [2].

Cuttlefish and octopuses are tasty and eagerly sought by predators. They are soft-bodied creatures without protective shells or sharp claws to defend themselves (Figure 2), so they must be able to hide or escape. Octopuses and cuttlefish are clever and can figure out

CEPHALOPODS

Free swimming marine molluscs such as the octopus, cuttlefish, squid, and nautilus.

NAUTILUS

7 species with approximately 90 tentacles—the most ancient cephalopods (known as living fossils) and the only cephalopods with external chambered shells (that form a beautiful spiral). Sizes range from 10–25 cm (8" to 25").

Figure 1

The evolutionary path of humans (vertebrates) and cephalopods (invertebrates) diverged a long time ago. The class of cephalopods, shown in the upper left of the figure, that includes octopus, cuttlefish and squid, diverged in the evolutionary tree from a common ancestor with vertebrate animals about 530 million years ago. The intelligence of cephalopods rivals that of the smartest birds and great apes. Reprinted with permission from Schnell et al. [1], licensed under CC-BY4.0.

SQUID

~300 species with elongated bodies, eight arms and two retractable tentacles—rapid swimming predators that move by jet propulsion, who grab prey with their long tentacles and their eight arms to hold and control their prey. Sizes range from tiny squid of 1 cm (1/2") to the Giant Squid that measures 13 meters or more (40').

which disguise is most likely to fool a potential predator. If a cuttlefish encounters a predator that relies on its vision to find its prey, the cuttlefish might use its chromatophores to display gigantic "eye" spots on its body. This disguise can fool the predator into thinking the cuttlefish is enormous, which frightens the predator away. However, if the predator uses chemical sensors (such as smell) to find its prey, the cuttlefish recognizes that even its best visual camouflage or disguise will not help—and will instead will either freeze or flee [3]. Cuttlefish even hold their breath, (which decreases the electrical activity in their bodies, reducing their chances of being detected by predators that rely on electroreception to hunt). As a last resort, they flee to safer grounds. Cephalopods can also use their camouflage powers, not only to escape from predators, buts to sneak up on and ambush prey.

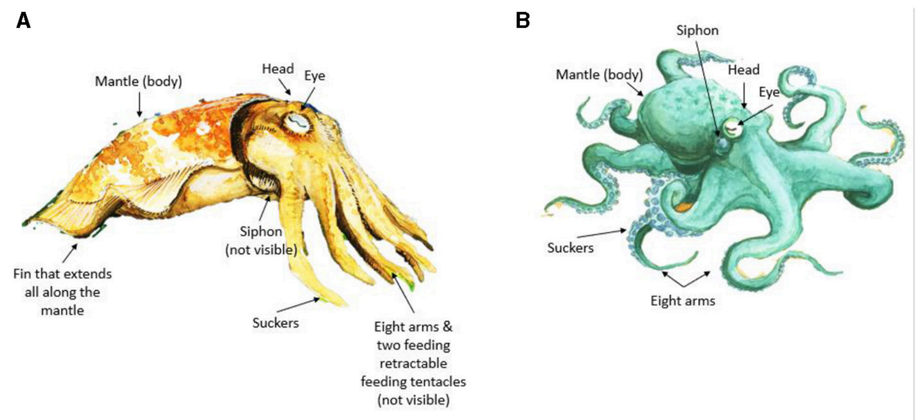

Figure 2

Scientists have determined that the ability of a cuttlefish to camouflage is not purely automatic and reflexive, but can also be shaped by decision-making. Cuttlefish make decisions about when to camouflage based on the presence of threats, and what they have learned over time. For example, cuttlefish can be taught to break their camouflage for a learned food reward [4]. Because the ocean is a dangerous place for the soft-bodied cephalopod, octopuses often travel incognito, using their incredible disguises as the equivalent of the "invisibility cape" in Harry Potter. For example, an octopus will slowly and inconspicuously slide across the ocean floor by mimicking a rock, in a sly "moving-rock trick." Octopuses are masters of disguise, and can also disguise themselves as moving algae, sponges, or even as a venomous lionfish. It is still a mystery how the octopus sends out correct commands to the thousands of "camouflage cells" in its skin so that it blends in perfectly with its surroundings, especially since the octopus is color blind! Learning more about the stealthy skin tricks of cephalopods will reveal how their brains controls their camouflage; and may also teach us how to develop "smart" camouflage technology in the future.

OCTOPUS

~300 species of soft-bodied cephalopods with eight arms (ranging in size from a tiny octopus of 2 cm (1") to the Giant Pacific Octopus that spans 900 cm! (30')). They are incredibly smart, show intelligent adaptive behavior, and can change body shape and squeeze through small holes.

Figure 2

(A) Cuttlefish (left) and **(B)** Octopus (right). Two cephalopod cousins. Both cuttlefish and octopuses have special skin that can change to mimic and reflect the environment (Image credit: © Phineas Jones, flickr.com).

CUTTLEFISH

~120 species of soft-bodied molluscs with eight arms and two retractable feeding tentacles—and a distinctive internal bone—the cuttlebone, that helps maintain buoyancy (Sizes range from 15–50 cm (6" to 20"). Like octopuses, they are very clever, excellent at camouflage, and known as "chameleons of the sea").

CHROMATOPHORES, IRIDOPHORES, AND LEUCOPHORES

There are three layers of different "camouflage" cells in the skin of cephalopods. The outermost layer are chromatophores, which contain colored pigments (yellow, orange, red, brown, and black). Coordination can alter the overall color and pattern of its skin extremely rapidly, for protection and communication. Chromatophores work together with other specialized color-changing cells in the next skin layer (reflective iridophores) which can create iridescent displays. Finally, beneath the iridophore layer are the leucophores that control overall brightness. Together, all these cells combine to generate amazing camouflage and are also used for signaling and visual communication.

WHAT TOOLS CAN AN OCTOPUS USE?

Another example of cephalopod intelligence is their ability to use tools, sometimes in very sophisticated ways. Veined octopuses (*Amphioctopus marginatus*) have been observed carrying coconut shells around like mobile homes or camper vans, and as a protective armored covering, to defend themselves from predators (Figure 3) [5]. An octopus has even been observed stacking up multiple coconut shells, and jogging across the seafloor, carrying them for up to 50–60 feet! Octopus will also hide in clam shells. In another example, octopuses have been shown to use their suckers to grasp objects and armor themselves with a shield of shells and stones, to protect themselves from sharks (as shown *in "My Octopus Teacher"* and in the BBC *Blue Planet II* series) [6].

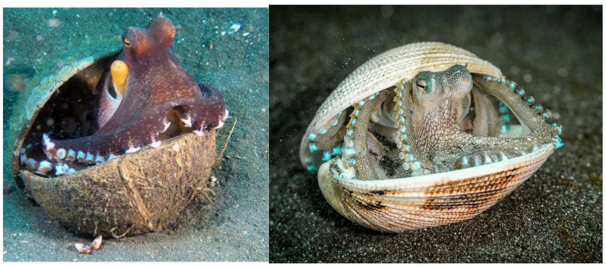

Figure 3

Figure 3

(Left) An octopus hiding in a coconut shell (Photo credit: Massimo Capodicasa). **(Right)** An octopus hiding in a clam shell. If threatened, the octopus will pull the other half of the coconut (or clam) shell tightly over its head to cover itself completely, for self-protection (Photo credit: Samuel Sloss).

OCTOPUSES LIKE TO PLAY, TOO!

Have you ever tossed a ball with a friend or played with a floatie in a pool? Octopuses like to play in a similar way too. Scientists have observed octopuses playing with floating objects in their tanks (to learn more about this, see this Frontiers for Young Minds article). Sometimes, they will toss a small object between their many arms, just to entertain themselves. At other times, an octopus might squirt jets of water out of its siphon to propel a floating plastic bottle from one end of its tank to the other. When the bottle floats back to them, they'll catch it and then squirts it off away again. While playing does not help an octopus find food, this playful behavior shows us that the octopus is curious in nature and experiences positive emotions. Octopuses will only play if they feel safe and content, just like most kids. Evidence of playful behavior is yet more evidence that cephalopods are smart.

PAPILLAE

Special group of "camouflage" cells in the octopus and cuttlefish skin which work by a unique hydrostatic mechanism under neural control that help these animals to change body shape to match the fine 3-D texture of their surroundings, so they perfectly blend in.

EPISODIC MEMORY IN CUTTLEFISH

Cuttlefish, like kids, remember past events and unique experiences in their lives. This type of recollection is called **episodic memory**. As an example, you may recall where and when a special birthday party occurred and what happened at that party. Cuttlefish have been shown to have this "what-where-when" type of memory, which

EPISODIC MEMORY

The ability to recall your previous experiences in their specific context of time and place (what-where-when an event occurred).

helps them improve their hunting behavior by remembering unique past foraging events that inform them about what they have eaten, where they have eaten it, and how long ago [6–8]. They can also remember the source of the memory, for example which sense they used—whether they saw it or smelled it, for example [9]. Furthermore, they make future-oriented decisions, such as choosing to eat less crab for lunch if they know their favorite shrimp dish will be served at dinner time [10].

CAN CUTTLEFISH PASS THE "MARSHMALLOW TEST"?

You may have heard of the famous marshmallow experiment, developed by a psychologist named Mischel et al. [11], in which young children were given one marshmallow, and told that they could eat it right away, or, if they waited for 15 min, they could have two marshmallows (Figure 4). This experiment studies **delayed gratification**, which means the ability to wait for a greater reward. Kids with stronger self-control could wait longer for the bigger reward, which could be helpful in achieving other goals later in life. What do you think you would you do?

DELAYED GRATIFICATION

The ability to resist the impulse to take an immediately available award in the present (like one marshmallow), in order to obtain a bigger reward (more marshmallows!) in the future.

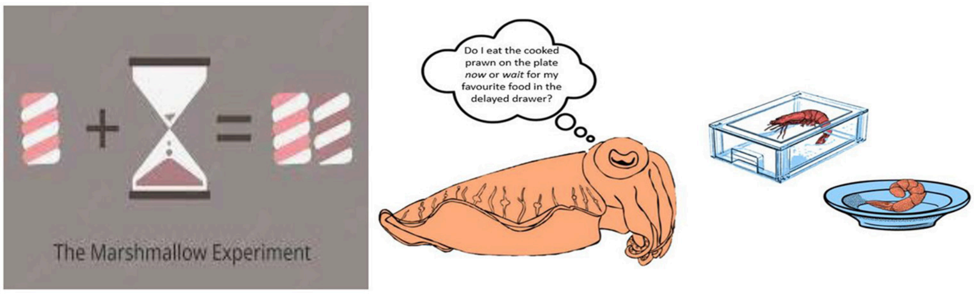

Figure 4

Figure 4

(Left) In the original "marshmallow" experiment," children could choose between eating one marshmallow right away, or waiting 1 min to get two marshmallows. **(Right)** In the cuttlefish version of the "marshmallow" test, cuttlefish chose between a cooked prawn that was available immediately, or could wait for a live shrimp (their favorite food) that would only be released after a delay. Cuttlefish waited up to 2 min for their favorite food! (Cuttlefish image credit: Paul Downy, flickr.com).

Comparative psychologists have used versions of the marshmallow test and investigated many species, to see which ones have similar self-control abilities to forego smaller rewards in the present and wait for bigger rewards in the future. Some species (mice, rats, chickens, and pigeons) are not very good at such self-control tasks, whereas other species (chimpanzees, crows, and parrots) have a remarkable ability to delay their gratification.

A recent study [12] has shown that cuttlefish (*Sepia officinalis*) have incredibly good self-control. The researchers discovered this, not by using marshmallows, but by giving the cuttlefish a choice between eating a good, but only so-so treat (a cooked king prawn) right away, or waiting longer for their favorite delicacy (live grass shrimp). They found that the cuttlefish were willing to wait for 2 min for the better reward. Moreover, the researchers also discovered that the individual cuttlefish that showed the best self-control on the cuttlefish version of the "marshmallow" test, also did better on a different learning task, suggesting a link between self-control and intelligence.

So, how did cuttlefish evolve this impressive level of self-control and future-oriented foraging abilities? Well, cuttlefish spend most of their time camouflaged and hidden, sitting and waiting for prey. When they forage, they break camouflage, so they are exposed to ocean predators that want to eat them. So perhaps because of this, cuttlefish have figured out how to optimize their foraging by learning to wait for better quality food, which might minimize the chance of being eaten by predators.

THE UNIQUE CEPHALOPOD BRAIN

We know that octopus, cuttlefish, and squid have the largest brain-to-body ratios of all invertebrates. Are cephalopods really as smart as other intelligent animals, such as chimpanzees, elephants, or dolphins? Recent experimental and behavioral evidence, some of which we have described in this article, reveals that an octopus or a cuttlefish can use its intelligence, learning and memory for camouflage, defense, play, optimal foraging, and solving complicated problems. Cuttlefish live in groups and exhibit social awareness, complex group interactions and social intelligence. Based on these findings, scientists now believe that cephalopods are intelligent creatures that possess some cognitive abilities that are comparable to those of non-human primates (monkeys and apes). But unlike chimpanzees, or dolphins, or elephants, an octopus lives an independent life from birth, with no parents or teachers to learn from! To survive, octopuses must quickly learn everything on their own.

But how do cephalopods learn so quickly? Is there something special about their brains? Surprisingly, the brain structures of cephalopods are strikingly different than the structure of the primate brain. The brain organization of primates and cephalopods have dramatically diverged in the last five hundred and fifty million years of evolution since they last shared a common ancestor. While an octopus has about as many brain cells (neurons) as a cat or dog (about half a billion), instead of all its neurons brain cells being in the head, about half of an octopus's brain cells are distributed in its eight arms, to help control their flexible, individual movements (to read more about this, see this Frontiers for Young Minds article). Cephalopods are very intelligent, and as we have seen, they use their big, distributed brains to help camouflage their bodies, use tools, escape predators, hunt and capture prey, solve complex problems, and also have a sense of fun, and enjoy their leisure time to play!

The dramatic differences in brain structures between cephalopods and vertebrates leads scientists to believe that intelligence has evolved more than once, in different animals with entirely different types of nervous systems [8, 13, 14]. In a way, compared to vertebrates, cephalopods are like an alien intelligence on our own planet! Further studies and discoveries will help us learn more about our brilliant cephalopod relatives and reveal new insights about their brains, minds, and behaviors.

ACKNOWLEDGMENTS

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ORIGINAL ARTICLE

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CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

ALICE, AGE: 11

Hi! My name is Alice and I am 11 years old, I love animals and nature, so I have a dog called Ginja, a rabbit called Jubas Escariote, and an axolotl called Bino. I love drawing, painting, music, and sports to. My favorite color is water green. I love adventures and make prank, I am very friendly and funny. And I want to thank my classmate Olivia because she helped me speaking English.

CLAUDIO, AGE: 15

I love science and physics, as well as learning about computer programming. I also love basketball. Go Celtics!

AUTHORS

ALEXANDRA SCHNELL

Alexandra Schnell is a comparative psychologist and a Research Fellow at Darwin College at the University of Cambridge. Her current research focuses on comparing learning, self-control, memory, and future planning abilities in cephalopods (cuttlefish and octopus) and corvids (jays, crows, and ravens). She has also studied elephants, freshwater fish, and juvenile crocodiles. Alex has a background in marine biology and has always been fascinated by life in the ocean. She is currently working as a film producer and storyteller for National Geographic's new series "*Secrets of the Octopus*," which will be broadcast on Disney Plus in April 2024.

LYNNIE FEIN-SCHAFFER

Lynnie Fein-Schaffer is a science education analyst at the National Science Foundation. Lynnie enjoys educating the public—and especially kids!—about neuroscience topics. She is interested in child development, enjoys hiking, getting outdoors, and spending time with her cat, who prefers the comforts of home.

JONATHAN B. FRITZ

Jonathan Fritz is the program director in Cognitive Neuroscience at the National Science Foundation. He has studied the neural basis of attention, perception, learning, and memory, and intelligence in zebrafish, mice, bats, ferrets, monkeys, and humans. Jonathan loves observing wildlife and likes to share the excitement of science with kids, especially new discoveries about our amazing brains. Cephalopods have evolved big brains, too! So, what do they do with them? Jonathan has become deeply fascinated by the incredible camouflage abilities and extraordinary intelligence of cephalopods—and impressed by their accuracy in squirting him with ink if he comes too close. *jonathan.b.fritz@gmail.com

NICOLA CLAYTON

Nicola Clayton is a Professor of Comparative Cognition in the Department of Psychology at the University of Cambridge and a Fellow of the Royal Society. She is also a visiting professor in China at Nanjing University's Institute of Technology and the Beijing University of Language and Culture. Her interests lie in the processes of thinking with and without words, combining empirical studies of cognition with observations of movement and other behavioral and communicative patterns, and how these inform comparisons between the cognitive abilities of corvids (members of the crow family), cephalopods and children. She is scientist-in-residence and associate artist at Rambert (formerly Ballet Rambert). She has won many awards for her research and, most recently, has recently been honored in 2022 by the Association for the Study of Animal Behavior (ASAB) and awarded the Tinbergen Award and Association for the Study of Animal Behavior SAB medal in 2022.