Study proposes explanation for how cephalopods see color, despite black and white vision

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According to a new theory, the pupil of the cuttlefish *Sepia bandensis* maximizes chromatic blur, allowing the animal to detect color. Credit: Roy Caldwell, UC Berkeley

For years, camera-makers have sought ways to avoid chromatic aberration—the color fringes that occur when various wavelengths of light focus at different distances behind a lens.

But where photographers see a problem, some sea creatures see possibility.

A new study, co-authored by the father-and-son team of Christopher and Alexander Stubbs, suggests that chromatic aberration may explain how cephalopods—the class of animals that includes squid, octopi and cuttlefish—can demonstrate such remarkable camouflage abilities despite only being able to see in black and white. The study is described in a July 4, 2016 paper in the *Proceedings of the National Academy of Sciences*.

"There's been a long-standing paradox that (cephalopods) manifest these vivid chromatic behaviors," Christopher Stubbs, the Samuel C. Moncher Professor of Physics and of Astronomy, said. "That would lead any observer, even a lay person, to conclude that they must be able to deduce things about coloration."

"I have always been fascinated by these animals, and have had the opportunity to watch them perform their camouflage act while conducting field work in Indonesia," Alexander Stubbs, a Berkley graduate student and lead author of the study, said. "We believe we have found an elegant mechanism that could allow these cephalopods to determine the color of their surroundings, despite having a single visual pigment in their retina."

But what would possess a Harvard physicist to devote time and energy to one of the most persistent mysteries in biology? For Stubbs, the answer is simple—his son.

"He chased me down with an idea he'd come up with, and the more we talked about it, the more sense it made," he said. "I credit my co-author with having the a-ha moment here."

That a-ha moment, Christopher Stubbs said, was the realization that cephalopods could potentially detect color by adjusting the focal position of their eyes to detect different wavelengths of light, and then composite each into a "color" image of their world.

"You can think about it like a digital camera dithering back and forth to find the crispest image," he said. "To me, what's really persuasive about this argument is...the pupils in these animals are an off-axis U shape, and that actually maximizes this chromatic signature at the expense of image sharpness. So it actually looks like there's been selective evolutionary pressure for their pupil shape to maximize this phenomenon."

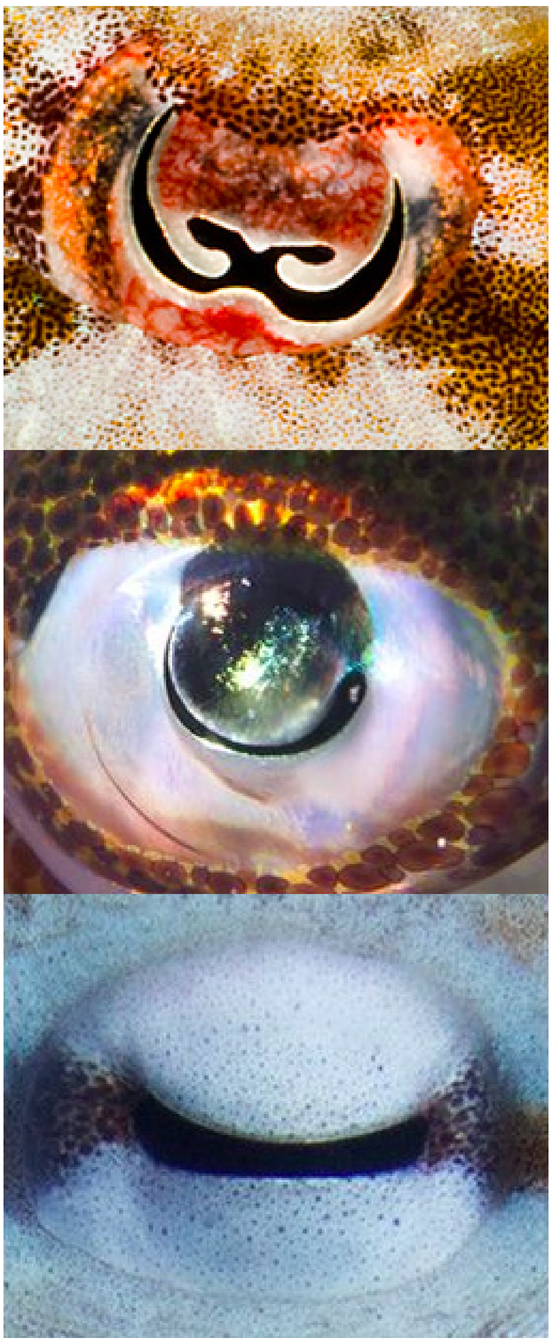
To understand just how cephalopods might take advantage of chromatic aberration, Christopher Stubbs turned to code he's earlier written for astrophysics research and created a computer model of how the animals' eyes work.

"People have done a lot of physiological research on the optical properties of lenses in these animals," he explained. "We wrote some computer code that essentially takes test patterns and moves the retina back and forth, and superimposes that on the image and then measures the contrast."

Though it's not definitive evidence of how cephalopods understand color, Christopher Stubbs said the mechanism described in the study does agree with earlier studies of cephalopod eyes.

"I'm not a life scientist, but I think in some ways, this is such an elegant mechanism that it would be a shame if nature didn't capitalize on it," he said.

Ultimately, Alexander Stubbs said, the hope is that the study will offer other researchers a direction for study in the search for a conclusive answer to how squid and octopi became masters of camouflage.



The unusual pupils of cephalopods (from top, a cuttlefish *Sepia bandensis*; squid *Sepioteuthis*; and *Octopus vulgaris*) allow light into the eye from many directions, which spreads out the colors and allows the creatures to determine color, even though they are technically colorblind. Credit: Roy Caldwell, Klaus Stiefel, Alexander Stubbs, respectively

"This is an entirely different scheme than the multi-color visual pigments that are common in humans and many other animals. High-acuity "camera style" lens eyes in octopus, squid and cuttlefish represent a completely independent evolution of complex eyes from vertebrates so in some sense we shouldn't necessarily expect that this lineage would solve problems like color vision in the same way. These organisms seem to have the machinery for color vision, just not in a way we had previously imagined."

Alexander Stubbs said. "We also conducted an in-depth review of prior literature evaluating conflicting evidence for color vision, and found prior behavioral studies suggesting a lack of color vision represent special cases and are consistent with our model. We hope this study will spur additional behavioral experiments by cephalopod community."

More information: Spectral discrimination in color blind animals via chromatic aberration and pupil shape, *PNAS*, www.pnas.org/cgi/doi/10.1073/pnas.1524578113

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