Visualizing deep-sea eye adaptations using micro-CT 3D reconstructions

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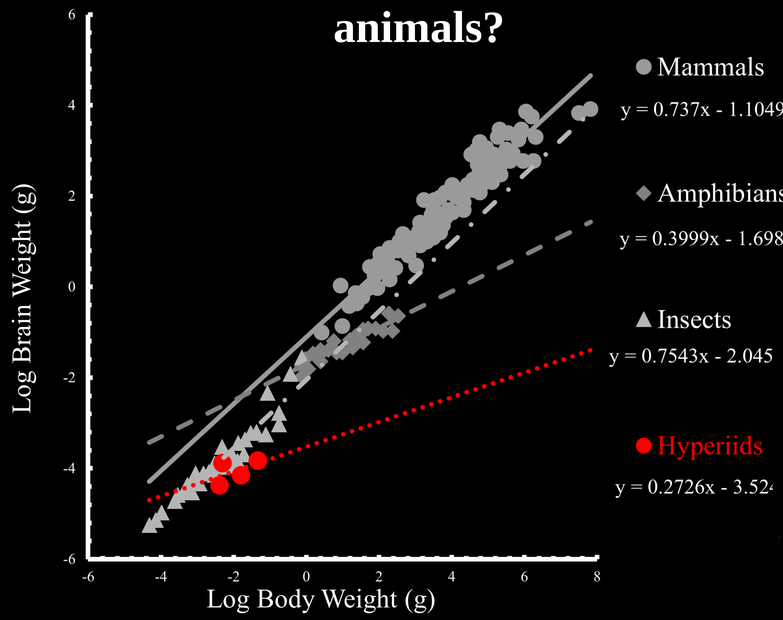
Background:

Hyperiid amphipods are small crustaceans that live in the midwater, below the surface but above the sea floor, where light diminishes exponentially with depth and there is nowhere to hide from predators. This group of animals have developed an extraordinary variety of eyes, at least 11 distinct types, across ~350 species, many of which are gigantic in size with various complexity. How do these eyes and their brains compare to each other and to other animal groups? We determined the volumes of eyes, brains, and bodies of six hyperiid species using 3D reconstructions from x-ray micro-computed tomography (µCT).

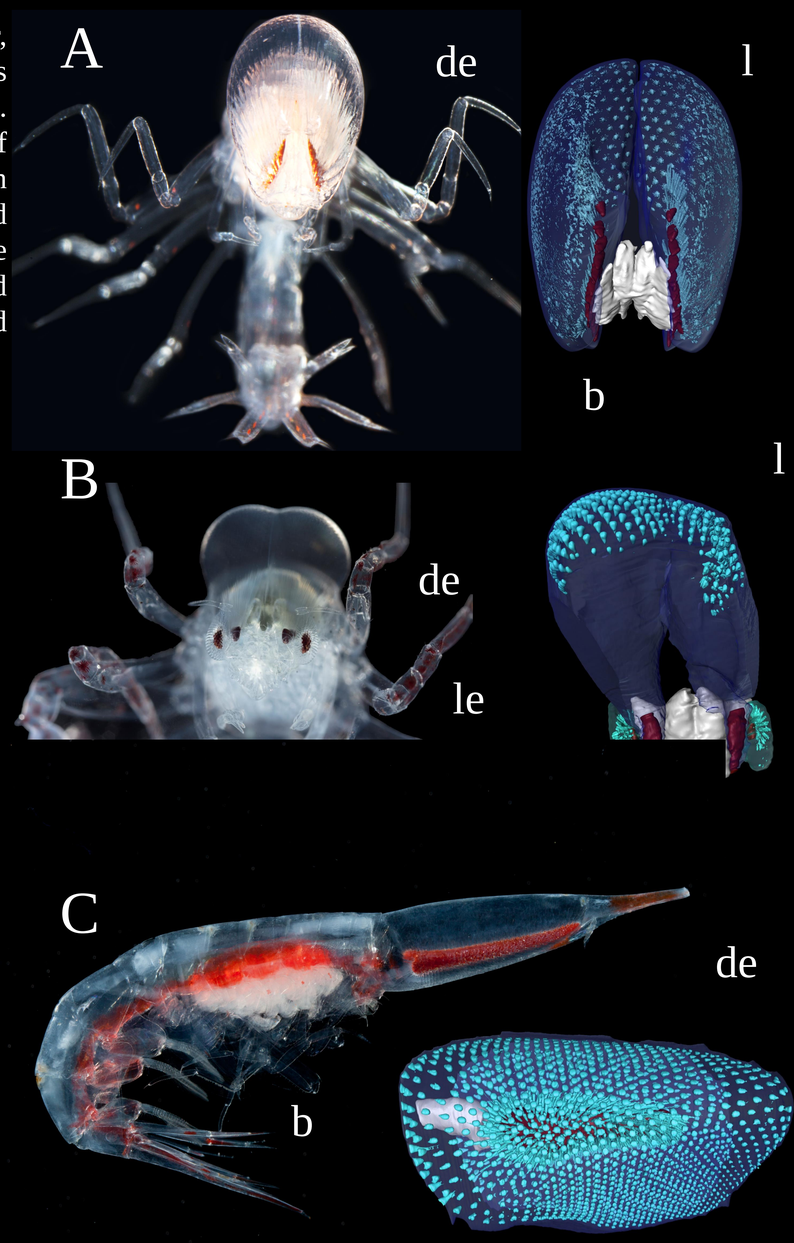
How do hyperiid brains compare to other animals?



Correlation between the brain weight and the body weight of se known animal groups[1], including four hyperiids (red dots). Fo animal group, brain size increases with body size in a spe exponential rate, with insects being one of the highest comparat mammals[1,2]. Our study shows that the rate of brain size inc with body size in hyperiids is far smaller than those of other ani (red dotted line). Larger hyperiid species don't have equivalently larger brains, indicating a higher constraint in hyperiid brain development than in terrestrial animals.

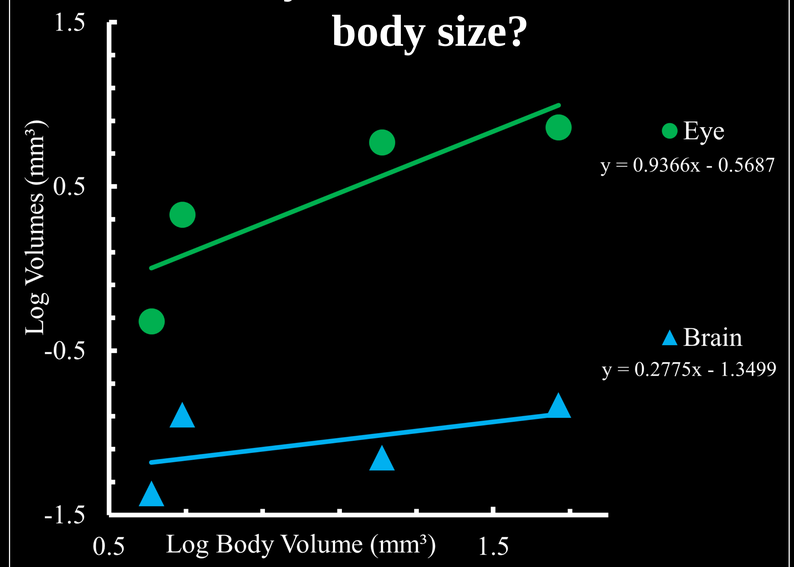
Methods:

- The eyes and individual eye components, brains, and the whole body of six hyperiid taxa were manually reconstructed from micro-CT imaging scans using Amira.
- *Hyperia*, *Paraphronima*, *Phronima*, and *Streetsia* had body volumes and were used for the brain-to-body and eye-to-body comparisons.



Exemplar pictures and 3D reconstructions of eyes and brains showing three distinct eye types of hyperiids. A. *Paraphronima*, one large pair of compound eyes with 34 discontinuous retinas (light sensors); B. *Phronima*, two completely separate pairs of compound eyes; C. *Streetsia* one pair of compound eyes with 360° visual field and a pair of cone-shaped retinas. b, brain; de, dorsal compound eyes; le, lateral compound eyes; l, lens.

How do eye and brain size scale to body size?



Correlation between the eye volume or brain volume against body volume of four hyperiid species with large compound eyes - showing their eyes are on average 40x larger than their brains (log 1.5). Both brain and eye tissue is energetically expensive to build and maintain. Possibly, hyperiids invest in large eyes for better low light vision, as larger eyes are more sensitive[3]. The trade off is then smaller brain size, but this may not be a problem for processing the homogenous, and thus quite simple, visual field of the midwater.

Conclusion:

We demonstrate that larger hyperiid amphipods have exceptionally larger eyes but smaller brains, a result that is distinctive from all other animals and likely indicates a unique adaptation to living in the midwater.

Future Directions:

- Reconstruct hyperiids with smaller eyes to better cover the full ranger of hyperiid diversity.
- Eberhard & Wcislo states that absolute brain size may not change but specific brain centers could in response to eye size[1]. Isolate and quantify visual centers of hyperiid brains and compare to total brain, eye and body size.

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