Squid

Common cuttlefish *(Sepia officinalis)*

# Unbeatable

As mentioned on page 39, the eyes of mantis shrimp are incredibly well developed – far superior to those of other crabs, and far more complex than the eyes of most other animals. In some species, these precision instruments may consist of up to 10,000 ommatidia. The central strip is not only able to analyze 100,000 colors, but also ultraviolet and polarized light.

Mantis shrimp *(Odontodactylus spec.)*

J. Marshall et al. **Behavioural evidence for polarisation vision in stomatopods reveals a potential channel for communication** (1999): Current Biology 9 (14): 755-758
T.-H. Chiou et al. **Circular Polarization Vision in a Stomatopod Crustacean** (2008): Current Biology. 18, S. 429
J. Marshall, M. F. Land, C. A. King, T. W. Cronin **The compound eyes of mantis shrimps (Crustacea, Hoplocarida, Stomatopoda)** in **Compound eye structure: The detection of polarized light** (1991): Phil. Trans. R. Soc. Lond. B 334: 57-84.

**Spatial vision with only one eye**

The eyes of a mantis shrimp (the photos depict an *Odontodactylus scyllarus*) share much of their structure with the apposition eyes of other crabs. Their central part, consisting of six ommatidia rows, divide the eyes into upper and lower hemispheres. The optical axes of the six rows are exactly parallel and directed forwards, while the first rows of both hemispheres cross over each other, being slightly inclined towards the center.

The outer rows run in parallel to the central rows, and the further they are from the middle, the more inclined they become towards the outer side. This construction, unique among animals, allows the crab to see a triple image with a single eye – thus, spatial vision becomes possible. While the upper and lower hemispheres serve the detection of shape and motion, the highly complex sensor in the middle, with its six rows of ommatidia, is responsible for the detection of colors and polarization. This sensor's angle of view is not especially large, spanning only about 10-15 degrees. Due to its independently flexible eyes, the crab is able to use one eye to assess an object's shape, while using the other to detect its colors and polarization.

**Seeing and interpreting polarized light**

Depending on the sun's location on the firmament, the polarization pattern changes as the light hits the atmosphere. Determining the sun's position on a completely overcast sky is among the skills of animals capable of detecting the orientation pattern of waves. Honeybees, among other species, use this skill to their advantage. A hitherto unknown pattern recognition was also discovered in mantis shrimp *(Stomatopoda)*, which were found to be able to detect circular polarized light. Such light can be imagined as a sort of spiral, where the polarization plane rotates in the light's propagation direction. Crabs are even capable of distinguishing between light polarized in a left and right direction. This form of perception plays a role during mating behavior and remains completely hidden from other animals. Artificial polarization filters accomplish the same task during DVD or CD playback, and also in some types of cameras. These manufactured filters, however, are only able to work with one color of light, while the eyes of mantis shrimp excel almost perfectly across their whole visible spectrum – from near-ultraviolet to infrared. So far, similar reflection patterns have only been observed in Glorious Jewel Scarab *(Chrysina gloriosa)*.

# Are eight eyes better than two?

**From facet eyes to lens eyes**

Terrestrial arachnids descend from ancestors living in the sea. It is thought that the facet eyes of these ancient animals regressed as they made their move onto land in the Silurian. At first, only five lenses remained, which themselves were composed of multiple fused ommatidia. In later generations this number was reduced to only three small lens eyes. However, these were accompanied by a larger pair of median eyes. This led the majority of primitive arachnids – the scorpions – to have a total of eight eyes. The pair of median eyes quickly evolved into their primary visual organ, while the lateral lenses mainly serve the differentiation of light from darkness and the detection of prey in motion (see page 105 on the bottom right).

**Primary and secondary eyes**

Real spiders (Araneae) have retained this set of eyes. They are thus equipped with one pair of large median eyes, which have, as in other arachnids, evolved into their most potent visual organs. In real spiders, they are often called primary or anterior median eyes, while the other six (three on each anterior side) are called secondary eyes. Depending on the group of spider, however, these smaller eyes may be very differently distributed – thus, many families of spiders are recognizable merely based on the positioning of these eyes. One pair of secondary eyes is often located next to the median eyes and is thus referred to as the front lateral eyes.

**Jumping spider: Inverse retina and a large focal length**

From the point of view of their construction, the primary and secondary eyes differ in that the latter are often inverse, while the secondary eyes are always everse. The inverse retina is always coupled to a *tapetum lucidum*, allowing light to be reflected. Jumping spiders possess no less than four (tetrachromatic) receptor cell types, which also happen to be very numerous. The strongly enlarged and forward-facing main eyes are equipped with big vitreous bodies, which produce large focal lengths.

Jumping spider from Thailand *(Siler semiglaucus)*

F. G. Barth **A Spider´s World: Senses and Behavior** (2002): Springer-Verlag, Berlin-Heidelberg-New York, p. 394
D. Neuhofer, R. Machan, A. Schmid **Visual perception of motion in a hunting spider** (2009): J. Exp. Biol. 212(17): 2819-23
T. Nagata, et al. **Depth Perception from Image Defocus in a Jumping Spider** (2012): Science 335 (no. 6067): 469-471

georg.glaeser@uni-ak.ac.at

**Four retinal layers for the estimation of color and distance**
The lens is focused on the four underlying retinal layers depending on the wavelength of light. The lowest two layers are receptive only to green color, however, the image is only sharp on the lower one. This difference in sharpness between the two retinas is used by the animal to estimate the distance of an object.

**Spatial vision by a movement of the retina**
Through a rotation of their anterior bodies, jumping spiders are able to quickly and noticeably change the direction in which they look. In addition, the retina can be moved by three pairs of muscles such that the spider can extend the visual field of its main eyes, leading to an overlap with the auxiliary eyes – thus allowing for spatial vision. A sharp color image of prey or partner can be seen at distances exceeding 10 cm. These spiders are able to estimate distances by comparing degrees of sharpness with respect to the focal plane – a strategy that we, as humans, also employ. However, spiders are able to see much more with eight eyes than with just two.

**A cooperation of eyes**
There exists something like a division of labor between these eight eyes. Aided by six muscles, the main eye is able to scan and analyze an object at the focus point of the remaining eyes.

**For many other spider species, vision is not so important**
Not all spiders have such a sophisticated pair of primary eyes. Depending on their lifestyle – whether diurnal or nocturnal, and whether sitting on cobwebs or on flower blossoms – these eight eyes may vary significantly in size and positioning. The lower image shows a crab spider that lives as an ambush predator on blossoms, preying on insects that feast upon the flower's nectar. Their eyes play only a subordinate role in this endeavor, which explains their small size. Tarantulas likewise have only small eyes, as they are able to localize their prey by detecting vibrations on their elaborately woven webs before stunning their unfortunate victims with their poisonous claws.


Goldenrod crab spider
*(Misumena vatia)*