Cuttlefish camouflage: a complex visual task

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Cuttlefish *(Sepia officinalis*) have a large repertoire of body patterns for camouflage and are capable of changing their patterns within a fraction of a second. Although there is variation in the details of these patterns, the variations fall into three camouflage categories: (1) uniform/stipple, (2) mottle, and (3) disruptive (Fig. 1). The expression of camouflage body patterns is a visually driven behavior, and in laboratory as well as field studies it has been shown that certain background variables - such as contrast, brightness, edge and size of objects - are crucial for the expression of these patterns. Uniform, Mottle and Disruptive patterns can each be evoked using natural or artificial substrates that are characterized by a specific set of parameters.

Here, we present a collection of studies that focus on unraveling the principles of visual control of camouflage in cuttlefish. Evidence is presented that uniform, mottle and disruptive patterns are reliably evoked using specific substrates, and that cuttlefish perform this intricate task of camouflaging themselves despite being color blind. Recently, we have put the camouflage patterns to the test: do cuttlefish truly match the colors of natural backgrounds? We present quantitative spectrometer measurements to answer this question. We recently discovered opsin expression in the skin of cuttlefish, which may help explain how colorblind camouflage is achieved. The eyes of cuttlefish are also unusual in that their pupil has a characteristic W-shape. We present evidence how this pupil affects the animal's visual field.

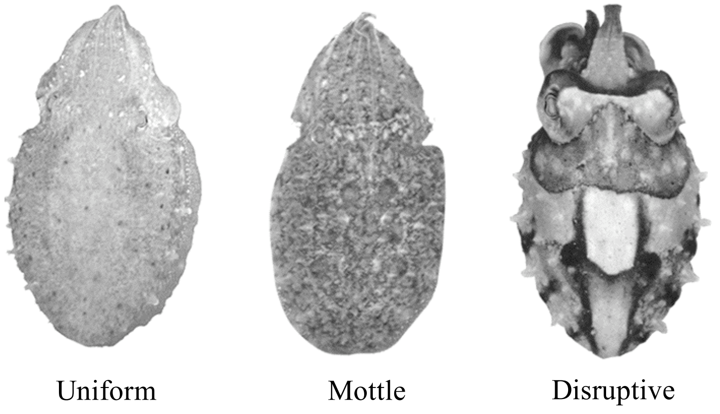
Uniform Mottle Disruptive

Fig. 1. Three characteristic cuttlefish camouflage patterns.

Eye development, pupil response and screening pigment migration in embryos and hatchlings of Southern calamari *Sepioteuthis australis*

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Eye development, pupil response and screening pigment movement in relation to light and dark conditions were analyzed in wild-caught, laboratory-incubated embryos and hatchlings of the Southern calamari *Sepioteuthis australis*. At the earliest developmental stage examined (at Steer et al 2003, developmental stage 18), the eye was comprised of a hemispherical cup of undifferentiated neural retina which, along with presumptive lentigenic and iris cell layers, enclosed a posterior eye chamber. Differentiation of proximal and distal processes of the photoreceptors was first evident in embryos of stages 22-24; however, the neural layers remained undifferentiated. In stage 26 embryos, the cornea had developed to form the anterior eye chamber, both outer and inner lens regions were apparent and crystallization of the lens proteins had commenced at the lens core. At stage 28, prior to hatching that occur at stage 30, differentiation of the retina was now complete. Longer photoreceptor distal processes were observed in the dorsal-posterior area of the retina, where a better sensitivity is postulated. At this stage, a light-evoked pupil response and migration of the screening pigment in the distal processes of the photoreceptors were also observed, with the degree of pigment migration varying in different regions of the retina. Results indicate that the visual system in Southern calamari is fully developed prior to hatching, thus indicating the importance of this sensory system during early life.

Diversity and evolution of optical designs realized in the compound eyes of several infralittoral Anomala (Crustacea, Decapoda) from the Western Mediterranean Sea

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It has generally been accepted that in terms of compound eye histological and fine structural designs, spectral sensitivity as well as optical capacity of individual ommatidia, the crustacean compound eye displays the highest degree of diversity amongst all recent Euarthropoda. However, most of what we know about compound eye diversity is essentially based on morphological and physiological research of large crustaceans like crabs, shrimps, lobsters, or stomatopods, whose ommatidial structures can be regarded as thoroughly understood. In contrast, the eyes of the Anomala, especially those of the Paguroidea, have been rather neglected, even if they were expected to have developed the highest number of optical types amongst all hitherto defined subgroups of the Decapoda. The ultrastructural anatomy of the ommatidia of those 20 paguroids, porcellanids, galatheoids and albuneids this study was based on considerably differ from the decapodan ground pattern. Besides quantitative variations from the ommatidial ground pattern of the Decapoda (2 corneageneous cells, four eucone cells, 7+1 retinula cell pattern), relevant structural and functional variations concerned the distribution of distal accessory pigment cells, the degree longitudinal expansion of corneageneous cells, as well as the arrangement and interaction of rhabdomeres. Furthermore, four classical and at least three intermediate types of apposition and superposition optics were found in anomalan ommatidia. With respect to the anomalan taxa examined, the presence of reflective superposition was limited to the Galatheoidea. Both morphological and molecular genetic data, which were obtained from mitochondrial 16S sequencing, indicate that the evolution of parabolic superposition and apposition eyes might have taken place several times independently in Paguroidea and Albuneidae, whereas the type of refractive superposition eye may have evolved only once in the ancestral lineage of the Paguridae. Following the principals of maximum parsimony, it is believed that the Galatheoidea have retained reflective superposition optics from the ommatidial ground pattern of the Decapoda. The assumed plesiomorphic state of apposition eyes with respect to all crustaceans does not contradict our concept as this state only applies to larval ommatidia (appearing in Zoea-larvae).

Filtering properties of the retina of box jellyfish

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Box jellyfish have a surprisingly elaborate visual system. It comprises of 24 eyes organized onto 4 rhopalia which each possess 6 eyes; 2 pit-shaped pigment cup eyes, 2 slit shape eyes and 2 lens type eyes. Box jellyfish are active and agile swimmers and are mostly found in visually complex environments e.g. mangroves. They display a range of visually guided behaviours, including phototaxis and obstacle avoidance. The presence of numerous eyes types, combined with a relatively simple nervous system leads us to believe that the visual system of box jellyfish is a collection of special purpose eyes, eyes which serve one or very few visual tasks. In contrast to general purpose eyes, the relevant information required for special-purpose visual systems is more limited and specific. Filtering of visual information can therefore be performed earlier in the special-purpose visual system, largely at the receptor level.

What visual task/s does each of the box jellyfish's eye type perform? To answer this question we must understand how the eyes filter visual information. Here we present results from our ongoing study of the electrical filtering properties of the retina of the lens eyes. In this set of experiments, we present the eyes with a variety of moving visual stimuli and record the responses of the lens eyes with extracellular electrophysiology. These experiments further our understanding of the visual stimuli which the lens eyes are tuned and brings us closer to elucidating the special purpose of the lens eye in box jellyfish.

Photoreceptor response in the box jellyfish *Tripedalia cystophora*

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The Caribbean species of box jellyfish *Tripedalia cystophora* lives in between the prop roots of mangrove trees. Here it feeds on swarms of copepods (*Oithona nana)*[1], which are attracted to light shafts penetrating the overhead canopy. *T. cystophora* is attracted to these light shafts as well[2]. Besides attraction to light shafts, another type of visually guided behavior is documented: the avoidance of dark obstacles[3]. This behavior will aid the jellyfish in avoiding the roots of the mangrove trees.

This study focuses on the response of the photoreceptors to light stimuli. With the final aim of understanding the processing that happens between the detection of a light stimulus and the initiation of behavioral responses.

Box jellyfish have four club shaped structures, called rhopalia, each carrying six eyes. Of these six eyes two eyes have a lens; the other four eyes do not possess a lens. The photoreceptors of the two lens eyes are most easily accessible, and their response is the subject of this poster.

[1] Scott E. Stewart, *Marine and Freshwater Behaviour and Physiology* **27** (2-3), 175 (1996).
[2] E. J. Buskey, *Marine Biology* **142** (2), 225 (2003).
[3] A. Garm, M. O'Connor, L. Parkefelt et al., *Journal of Experimental Biology* **210** (20), 3616 (2007).