Most deep-sea fish have visual pigments that are most sensitive to wavelengths around 460–490 nm, the intensity maxima of both conventional blue bioluminescence and dim residual sunlight. The predatory deep-sea fish Malacosteus niger, the closely related Aristostomias sp. and Pachystomias microdon can, in addition to blue bioluminescence, also emit far-red light from suborbital photophores, which is invisible to other deep-sea animals. Whereas Aristostomias sp. enhances its long-wavelength sensitivity using visual pigments that are unusually red sensitive, we now report that M. niger attains the same result using a derivative of chlorophyll as a photosensitizer.

Aristostomias tittmanni has at least three visual pigments, based on two opsins, within its retina (absorbance peaks at about 531, 548 and 588 nm). For the dragon fish, M. niger, we isolated outer segments of the photoreceptor by suspending them in 20% sucrose solution, ensuring that minimal disruption was caused to the photoreceptor membranes. Only two visual pigments (absorbance peaks at 517 and 542 nm) were identified by partial-bleaching spectrophotometry of both detergent extracts (Fig. 1a,b) and fresh outer-segment suspensions (data not shown).

Spectrophotometry identified these two pigments as a rhodopsin/porphyropsin pair based on a single opsin bound to retinal or 3,4-dehydroretinal. We verified that there was only one opsin in M. niger by using degenerate primers based on the sequence of teleost fish genes encoding rod opsins, to degenerate primers, based on the sequence and dim residual sunlight. The predatory deep-sea fish genes encoding rod opsins, to degenerate primers, based on the sequence and dim residual sunlight. The predatory deep-sea fish genes encoding rod opsins, to degenerate primers, based on the sequence and dim residual sunlight. The predatory deep-sea fish genes encoding rod opsins, to degenerate primers, based on the sequence and dim residual sunlight.

Exposure to 671 nm, close to the absorption peak of the presumed photosensitizing pigment complex (Fig. 2), is more effective at bleaching the visual pigments than a 654-nm stimulus. If the stimulating light was bleaching the visual pigments directly, the 654-nm stimulus. If the stimulating light was bleaching the visual pigments directly, the 654-nm stimulus. If the stimulating light was bleaching the visual pigments directly, the 654-nm stimulus. If the stimulating light was bleaching the visual pigments directly, the 654-nm stimulus. If the stimulating light was bleaching the visual pigments directly, the 654-nm stimulus. If the stimulating light was bleaching the visual pigments directly, the 654-nm stimulus. If the stimulating light was bleaching the visual pigments directly, the 654-nm stimulus. If the stimulating light was bleaching the visual pigments directly, the 654-nm stimulus. If the stimulating light was bleaching the visual pigments directly, the 654-nm stimulus. 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To identify the putative photosensitizer, we analysed suspensions of retinal cells in 20% sucrose. The fluorescence excitation and emission spectra (Fig. 2a) suggest a magnesium-free chlorophyll derivative such as chlorophorbide a or pyropheophorbide a. When homogenized retinal suspensions were extracted in hexane/methanol, the photosensitizing pigment was entirely in the methanol phase, indicating that it possessed a free propionic-acid residue. Thin-layer chromatography of the chloroform extract of the methanol phase gave only one spot for the methyl esters of the photosensitizing pigment(s) that migrated at the same speed as the reference compounds, methyl chlorophorbide a and pyropheophorbide a, prepared from pure chlorophyll a (ref. 7).

The ultraviolet–visible absorption spec-
trum of the diethyl ether extract of this unknown compound(s) (Fig. 2a) was similar to that of standard samples of pheophorbide \( a \) and pyropheophorbide \( a \), and virtually identical with the spectrum of the methyl ester of chlorobium (Cbm) pheophorbide 650, fraction 2. The electron-impact mass spectrum for the methyl esters of the unknown compound(s) suggests that they are Cbm pheophorbides (a mixture of defarnesylated and demethylated derivatives of Cbm chlorophylls, series 650 and 660). High-intensity signals corresponding to the expected main fragments from Cbm pheophorbide 650 methyl esters suggest that the Cbm chlorophyll 650 derivatives predominate.

Energy transfer from the photosensitizer to the visual pigment may involve intersystem crossing to generate an excited triplet state (\( T_1 \)) of the pheophorbide, which could then transfer energy to the ground state of the visual pigment’s 11-cis chromophore to generate its triplet state. Such a triplet state of the visual pigment chromophore has been proposed as a normal intermediate of the visual pigment’s chromophore (a), with energy transfer to the ground state of that pigment.


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Vision and attention: the role of training

What happens to visual experience in the absence of visual attention? Does lack of attention render us effectively blind, or is there a significant residual experience? Here I show that the surprising results of a recent study \( ^7 \) were due not to the novel way in which attention was controlled, but simply to the use of novice rather than expert observers. So the evidence remains strong that some aspects of visual experience are essentially independent of attention.

Joseph et al. \( ^8 \) reported that observers are unable to detect a simple feature difference (‘popout’) when attention is taken up elsewhere in the display. This is at odds with previous reports \( ^9,10 \) and a large body of work on preattentive, parallel processing in vision.

Methodologically, the new study departs from earlier efforts by controlling attention with the help of an ‘attentional blink’. This is the lapse in perception that occurs, for example, when a predesignated target letter is recognized in a stream of letters appearing rapidly one after the other. Joseph et al. argue that attentional blink removes attention more effectively than the concurrent-task method used in previous studies."