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The Extended Sensorium

Polarisation Sensitivity: a Strong and Weak Sense

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Part 2 of 2

Mantis Shrimp

Not only does the mantis shrimp pack a serious punch, so fast that it can produce killer sonoluminescing bubbles, but these guys blow everyone out of the water in terms of a functional polarisation-sensitive visual apparatus, which we will now examine. The hyperspectral eyes of mantis shrimp which perceive from the infra-red to UV range (to 300 nm),[14] can also perceive linearly and circularly polarised light.

The tail of the male mantis shrimp, as well as other parts of their bodies, seem to emit circularly polarised light. When seen through a filter for left-circularly polarised light, and right-circularly polarised light, only one of these images of the tail will be illuminated.

The All-Seeing Mantis Shrimp.

It is unclear whether this is a kind of bioluminescence, a controlled reflection as in the case of the cephalopods, or simply the reflective nature of the material, although several articles imply that the males use this ability to "signal" others, implying that it is more than passive reflectivity.

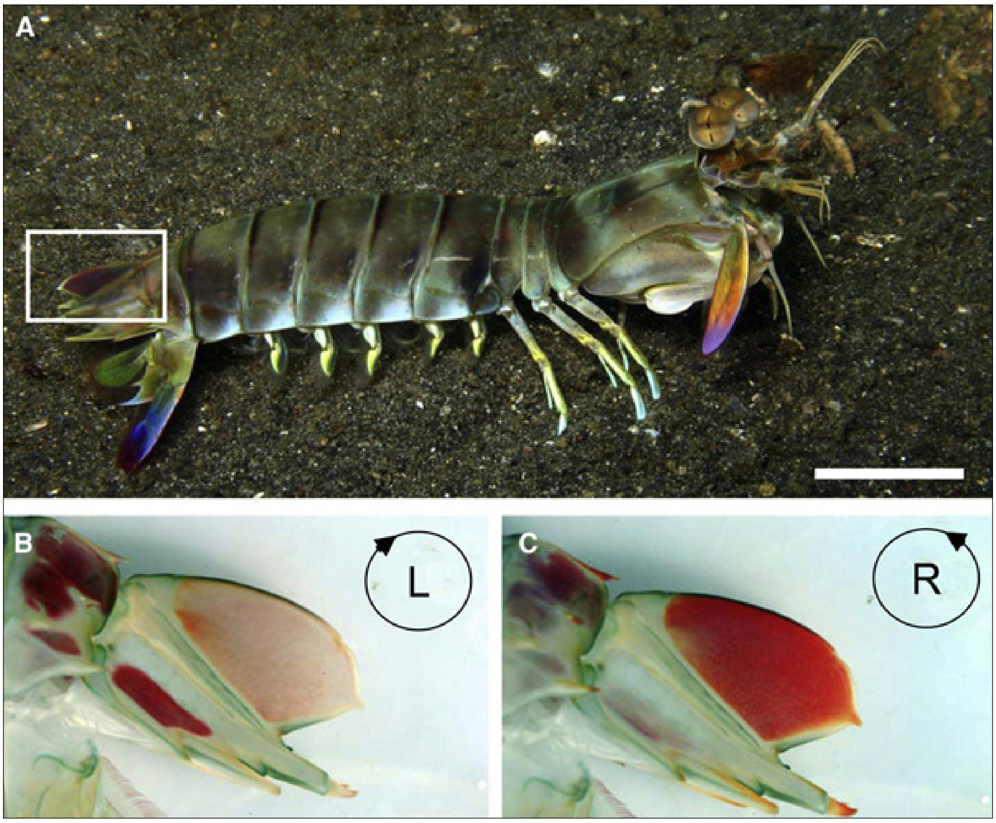
They have 12 primary colour pigments to our 3, and 4 which aid in polarisation sensitivity. Each eye alone has 3 distinct parts, the 2 hemispheres and the midband, and is capable on its own of trinocular vision.

This mid-band is where most of the action occurs, being composed of many ommatidia, or "simple eyes," each of which has long visual cells called rhabdom arranged and close packed in a star pattern, pressing up against the ommatidia, similar to the insect eye. Here also, as in the cephalopods, we have tube-like microvilli, the light sensitive part of the rhabdom, each of which points radially towards the center of the ommatidia, and which contains the pigment. Interestingly, more detailed studies reveal that the "small four lobed UV sensitive photoreceptor," R-8, in the midband, is also said to be the one responsible for the circular polarisation perception—two supersenses in one! *"Circular polarisation sensitivity is not innate to the R1-7 cells, but arises from the quarter-wave retardance of the overlying four-lobed R-8 cell."* [16] In some fish, and in bees and other insects, these two capabilities are related, that is, UV perception and polarisation sensitivity, but only for linearly polarised light.

Seeing the circularly polarised light is thought to be unique to several species of mantis shrimp, although fireflies and scarab beetles can generate it; scarab beetles reflect it off of their liquid-crystal like exoskeleton. One of several experiments used to detect the mantis shrimp's sensitivity was done by giving them food with a flashing left circularly polarised light signal above it. Next to this station, would be a flashing right circularly polarised light signal, but no food. [17] This would be repeated, and the positions of the two stations alternated, one with food, one without, but the light signals kept the same—the left circularly polarised light always at the station with food. When the food was removed, unbeknownst to the mantis shrimp, after having repeated this exercise many times, the mantis shrimp invariably went for the flashing left circularly polarised light signal. If this experiment were repeated with humans, our choice about which station to go to would have been arbitrary (or we might have a slight chance of making an informed guess, as we will soon see), whereas for the mantis shrimp, it would be informed by sensing some distinction, though we don't know exactly how this looks to them, between the left and right polarised light. How they sense the light is usually compared to the function of a quarter wave-plate, the non-biological mechanism we use to convert circularly-polarised light to linearly-polarised light. Accounting for the perceptive ability is based on this kind of quarter wave-plate being literally in the eye, in the R-8 cell overlaying the other rhabdom. It would be interesting to compare how our non-biological quarter-wave retarder in our labs is different from that in the mantis shrimp's eye—and they do appear to be different. Is it a unique kind of crystalline structure, as is the case for our wave plates, which are made of calcite, quartz or magnesium fluoride? It appears to be the case, but they are still quite different. The efficiency of their "wave plate" is said to be greater than even our own quarter-wave plates by a factor of 3. What accounts for this is unclear. As these researchers from Nature Photonics admit, the optical capabilities of the mantis shrimp eyes may be more advanced than some of our best noetic instrumentation:

"We have discovered a novel microvillar mechanism that acts as a remarkable achromatic optical device. Man-made retarders are among the most important and commonly used optical components, and the cellular structure we describe (of the mantis shrimp) significantly outperforms these current optics." [18]

This is aside from the fact that ours are not also used to perceive linearly polarised UV light! The question of how alike, in fact, are the means by which humans, with our instruments, and animals with their bodies, receive and produce polarised light is forcefully posed by the case of the mantis shrimp. We can ask ourselves, what does the world look



Mantis Shrimp Tail seen through left and right circularly polarised filters. Image courtesy of T. Chiou. [15]

like to this creature? And although the circular polarised vision seems the most exotic, it is also interesting to ask how this creature perceives colour? What does it look like to see based on the blending of 12 colour pigments? Would you see "different colours", or would variations be more striking? Would they blend differently? For a mantis shrimp, which colours would combine to make green? Blue and yellow, or completely different colours? What "colour" is infrared or UV light for this creature? What does the visual field of an animal who can see all kinds of polarised light look like? Or what does it look like to have one eye with trinocular vision? Two? As we extend our concept of the sensorium, there seems to be a gap between the supposed impressions of these supersenses, their actual perceptions, and the action of the creature, although these senses are not used for creativity. Some of what is unexplained lies within the "technology" itself. Although these creatures lack mind, untangling the problem of how these biological senses actually work, is a problem which continues to puzzle us, a problem of which these sea creatures, for example, are unaware, though they operate based on them to near perfection. Clearly a mantis shrimp and a human being do not see the same thing; the visual impressions received are thus, not real objects, but different, contrasting impressions received from different set of instruments. In the next case, we will show that our human visual map may have more resolution to it than we may assume from the most obvious impressions.

Humans & Haidinger's Brush

After reviewing some cases of super polarised vision, the human capability to perceive polarised light may seem rather lame: a faint blue and yellow bow which you may or may not be able to see on your laptop screen or on a blue patch of sunny sky close to the horizon. You probably think that seeing circularly polarised light was out of the question—but seeing a diagonal brush which maintains its orientation as your head tilts indicates that the light is circularly polarised, left or right depending on the tilt! But surely this isn't as useful as being able to communicate with other members of our species through secret polarisation channels.

The Haidinger's brush is what is called an entoptic phenomena, and was discovered in 1844 by German physicist, geologist, and mineralogist Wilhelm Karl von Haidinger. Similar to the floaters you may see "on your eye," the Haidinger's brush is also not something external. After all this discussion about the highly structured pigments in animal eyes, and our "practically random arrangement," how is this faint polarisation perception achieved? It's not completely settled. A recent article published in 2010 points out the flaws in a couple of theories, and posits their own, which they tested through creating an artificial eye and camera. The reasons for being able to see the funny pattern of polarised light here also trace back to an organisation of the eye's pigments. But as you see in this brief summary, completely different models were said to be able to account for its perception. The 2010 study references previous theories:

"Most models are based on either a possible radial or tangential arrangement of absorbing elongated yellow pigments in the macula. Unfortunately, a radial alignment of anisotropically absorbing molecules along the nerve fibers which may be expected for highly elongated pigments would lead to reverse brush colours. Tangential alignment of the molecules orthogonally to the fibers would lead to the correct colours, but are unexpected and has never been experimentally observed." [19]

The researchers who wrote this critique say that they can produce the correct brush colours and orientation based on a particular cylindrical organisation of a small population of blue cones in the fovea, a small section of the macula. They claim to have mimicked this organisation in an artificial eye-like device, and say that they were able to photograph an image generated by this device which produced the blue brush when blue light was shown, and the yellow brush when red and green light was shown. However, accounts of people seem to indicate that the brush is not perceived at all with red light, but that specifically blue light is required. The cause of the particular faint colours of the brushes is not clearly related causally to the colour of the perceived light, nor how or if it depends on the organisation of the eye's pigments, for example, radial or tangential, as implied above, where both could be used to explain the perception. Does it depend on yellow or blue pigments? Both explanations have been given. Another account suggests it may be a birefringence in the eye itself which accounts for the particular colours. As we can see, there are and have been many theories put forward. Many models claim to account for some aspect of the perception, but none claim to have reproduced it completely in the same way as the human eye.

It is nonetheless interesting that this last model should rely on a specific arrangement of the eye's blue cones, which are relatively sparse in the human eye anyway—only 2% of our cones are blue cones, but are highly sensitive for yet unexplained reasons. Most of us would not consider ourselves to be blue colourblind, despite having so few blue cones. In the area of the fovea, the percentage of blue cones is even less than 2%. Blue light has proved important for other phenomena referenced in this report, including bird magnetoreception, etiolation, and certain biological rhythms. But at least one account claims that the fovea is too small to account for the perception based on the size of the brush.

The above apparatus as described, a simple machine involving not much more than a lens, a glass cylinder, and a "blue mosaic on a screen," cannot be seriously treated as an analogue to the human eye. And also, interestingly, the unique arrangement of a very small number of blue cones, which this model relied on, does not, on the surface, account for other phenomena associated with the Haidinger's brush. As researchers are finding out, you may want to understand why you can see the Haidinger's brush, or why you can't, because it may have to do with your overall visual health.

The ability to sharply perceive the Haidinger's Brush in a particular eye, has been linked to the "dominant eye," also a puzzling phenomenon, in many people. But those functions which we associate with eye dominance, dealing with perception much more generally, do not on the surface account for why the dominant eye would be able to perceive a sharper Haidinger's brush. Apparently, the ability to see or not to see the Haidinger's brush is even used to diagnose some degenerative conditions in the eye:

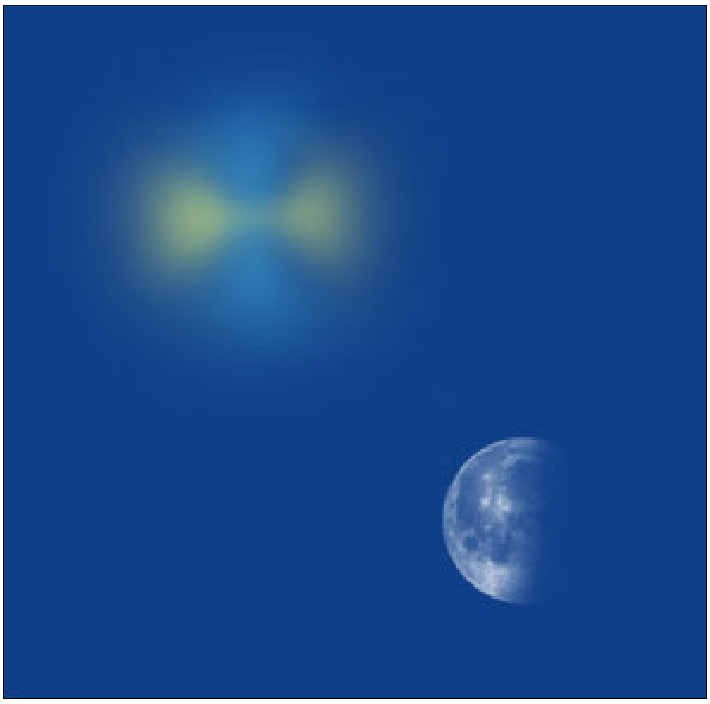
"The absence of a photographically visible polarisation pattern is an indication of macular dysfunction due to senior macular degeneration, angioid streaks, or diabetic retinoplaty, and thus the phenomenon can be useful for diagnosing diseases affecting the macula...Perception of Haidinger's brushes may indicate a healthy eye, and the inability of perception of these brushes indicates certain visual dysfunctions." [20]

Additionally, for people with certain kinds of strabismus, or "turning eye," patients can be trained to view objects with the correct part of their eye by lining up the Haidinger's brush with the object they are trying to look at.

We have, with the Haidinger's brush, a perception much less stark than those used by the bee, cephalopod, or mantis shrimp to function day to day, but which may be just that significant for our own vision all of the time, despite the fact that we aren't consciously seeing it all of the time. However useful the ability to perceive the Haidinger's brush may be for making the above diagnoses, it is only correlated with these various degenerative eye conditions—there is not a demonstrable causal connection between the them.

Perhaps we could refer to it as a kind of visual "weak force." That is, something barely perceived or sensed by us, as, for example, in the case of various low intensity kinds of radiation which play some critical role in the optimal functioning of an organism. Here, we have a faint, or low intensity perception, which seems to play some more criti-

Colourful Mantis Shrimp, close-up on eyes. Notice the darker midband especially in the image on the right. Image courtesy of flickr user:Silke Baron.



An exaggerated version of Haidinger's brush.

cal role for the function of vision. Perhaps the true cause for it would redefine our notion of vision itself—but with various and completely different models claiming to explain it, we are still not there yet.

Let us, as Riemann did for the investigation of the ear, start our investigations of vision based on first taking into account what the animal and human visual apparatuses *do*, and allow that to shake up our models of how vision must function.[21] It does seem to be clear, that based on the function of the human eye generally (and the very intentional role of human beings!) claims that anything about its organisation were random, as compared to the eyes of animals, seem more dishonest than anything. These kinds of statements should be reformulated to state that we don't fully understand the reasons behind the particular organisation of the eye. Then again, the eye itself exists and functions based on its own relationship to cosmic radiation, polarised, unpolarised, and of varying intensities. Is there a cause which lies completely outside of the domain of the rods and cones of the eye, as might also be the case for distinct closed eye visual noise, colours, and patterns, or those you see when pressing or rubbing a closed eye? Or the lights seen by numerous astronauts which appear when they close their eyes?[22] In addition, auroral "hearing," bird magnetoreception, the phenomenon of synesthesia, and the case of someone like Helen Keller, can all cause us to wonder if there is not more to vision as a sense altogether than we might have assumed from the most obvious impressions.[23]

And despite the greater intensity and clear utility of the animal polarisation sense, our own seemingly weaker visual perceptions do not leave us weaker as a species. But, could we further increase our power over nature through honing our own polarisation sense, through our man-made instruments and even our own biological instrument? Based on how much time most of us spend on a given day staring at an LCD screen on our laptop, it may be the case that we have been subconsciously training ourselves to block out the perception of the Haidinger's brush, as a kind of unwanted visual background noise. For Vikings who navigated the seas using pieces of Iceland Spar to locate the Sun on a cloudy day, the polarisation sense was like second nature, and a matter of survival. Perhaps some of them were unaware that it was polarisation which they were responding to, as you yourself might have been unaware of what generated the faint perception we have now identified as the human biological polarisation sense. What other kinds of weak impressions, or phenomena more generally, could you be responding to, unknowingly?

Footnotes

[14] For cell perception of UV below this frequency, see Cody Jones' report on Gurwitsch Mitogenetic Radiation.

[15] Chiou, et al, "Circular Polarisation Vision in a Stomatopod Crustacean." Current Biology (2008), doi:10.1016/j.cub.2008.02.066

[16] Kleinlogel, S, White AG (2008) "The Secret World of Shrimps: Polarisation Vision at Its Best." PloS ONE 3(5): e2190. Doi:10.1371/journal.pone.0002190

[17] "How Mantis Shrimp see circularly polarised light," August 16, 2010, http://arthropoda.southernfriedscience.com/?p=2964

[18] Roberts, N.W., T-H Chiou, Marshall, M.J., Cronin, T.W. (2009) "A biological quarter wave retarder with excellent achromaticity in the visible wave length region," Nature Photonics, Doi:10.1038/NPhoton/2009.189

[19] Le Floch, Albert, Ropars, Guy, et al. (2010) "The Polarisation sense in human vision," Vision Research 50, 2048-2054, doi:10.1016/j.visres.2010.07.007

[20] Gabor Horvath and Dezso Varju, Polarised Light in Animal Vision: Polarisation Patterns in Nature, http://www.uni-tuebingen.de/cog/literature/literatur-Dateien/2003/HoVa_bookcontensts03.pdf

[21] See Aaron Halevy's report on Riemann's approach to hearing.

[22] http://www.space.com/scienceastronomy/mir_lights_030416.html

[23] See Oyang Teng's report on Synesthesia and Sky Shields' on Auroral Hearing