Birds’ dependence on light when migrating

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Every year millions of birds travel the globe back and forth to escape the winter cold in the north. This outstanding journey is the result of natural selection, because the rate of survival has been higher for those birds that migrate to milder climate during winter time than for those who stayed. Their return to the north to propagate during the northern hemispheres springtime is probably due to the lesser competition for food – there are not as many individuals in the northern as in the southern hemisphere. Furthermore, since the sun stays up longer in the north during their spring and summer, it is easier for the birds to find food to their hungry youngsters. How birds can travel such great distances, as far as from northern Europe to South Africa without getting lost has interested scientists for years. Even the Baltic-German zoologist Alexander von Middendorf (1815-1894) was fascinated by this, and suggested already 1859 that they use the magnetic field of the Earth to navigate. Several theories how this works in practice have been suggested, for example that birds have magnetite grains in their beaks that react on magnetic fields which gives the birds information about directions. During the latest years a new theory has developed. It suggests that birds use the surrounding light, its intensity and wavelength, to navigate. Experiments with the European robin (Erithacus rubecula) support this idea since they turned out to be well oriented with monochromatic light of some wavelengths but not with others.

Light dependence – a bright idea

To use light as a part of a navigation system appears clever considering the virtually infinite source of light coming from the sun. It is a regular source which changes during the year, helping the birds to know whether it is summer or winter, day or night. They do this by comparing the number of hours with daylight with the hours of night-time.

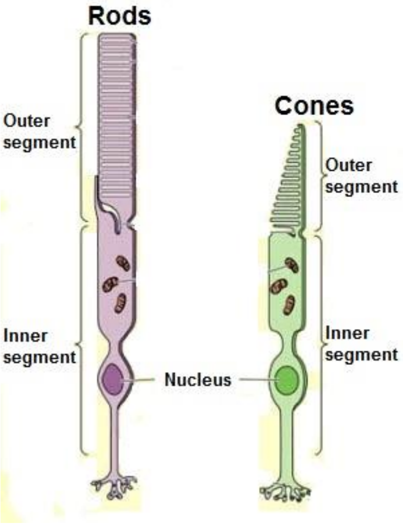

Figure 1. Schematic picture of the visual pigments rods and cones. *Revised after The Brain from Top to Bottom (Retrieved 2013-12-11).*

The physiology of birds’ eyes

The theory of light as an important factor for magnetoreception is a complicated one involving chemical reactions. It will take us down to the smallest components in the eyes, and much of the model is based on guessing. It is therefore of great importance to know a little about the physiology of birds’ eyes before we can understand how a possible light dependence work.

Rods and cones

Just as humans, birds have a large number of photoreceptors, called rods and cones, in the retina of their eyes (figure 1). In the outer segment of the distal end of the rods and cones there are photo pigments. The pigments absorb light in different wavelengths and therefore have different maximal sensitivity for different wavelengths. All the pigments contain a protein called opsin and a chromophore derived from vitamin-A, and it is the interactions between these two that determines the pigments’ sensitivity for different parts of the spectrum. Birds have one type of rods. This is the most light-sensitive photoreceptor, and therefore the one used at night. Rods are therefore present at a higher frequency in night-active birds than in day-active species. On the contrary to rods, birds have two types of cones, the single cones and the double cones. The role of the double cones seems to be in detecting movements and to provide a sharp image, i.e. resolve spatial details. The role of the single cones is to enable the birds to perceive colours and to differentiate them from each other. Birds have four different single cones, and they have different peak sensitivity, ranging from UV-radiation to the long wavelengths light that we human call red light, around 600 – 700 nm.

The photo pigments

The photo pigments, one in each single cone, are sensitive in different parts of the wavelength spectrum. Three of the cones absorb long wavelength light, from about 400 nm up to what we humans call red light, about 568 nm. The fourth cone-type absorb UV-light, around 350 nm, which is invisible to the human eye.

The oil droplets

Important to the cones' ability to separate colours is the fact that they have a small oil droplet in the inner segment of the distal end. All types of oil droplets, except for one, contain carotenoid – a substance that absorbs short wavelengths. The carotenoid in the oil droplets filters the incoming light before it reaches the photo pigments.

The number of cones in birds' eyes can depend on the different species' different lifestyles and habitats. Night-active birds, with their limited use of color vision, have therefore more rods then cones in their retinas.

Radical pairs

A model that would enable weak magnetic fields, like the Earth's, to affect chemical reactions in birds is the one commonly known as The Radical Pair Model. Radicals are molecules with an uneven number of electrons and with a constant spin on the single electron. Because of this they are highly reactive, which means that they easily can react with other molecules. Radical pairs is a phenomenon that occurs when two of these radicals exist in each other's demarcated proximity long enough to make their two single electrons spin to correlate. This process is induced by light.

Single or triplet state

The spin of the radical pairs can be antiparallel, which is called their single state, or parallel, which is called their triplet state. What state they are in is determined by the magnetic field since every electron spin is associated with its own magnetic moment. It is the conversion between these two states that helps the bird to navigate. Since the cones, where the radical pairs exist, are fixed at the retina, the birds can compare their position with the magnetic lines in the Earths' magnetic field. As I just mentioned, the cones are fixed, but when the bird moves through the magnetic field, and tilts its head or move its eyes, the angles between the magnetic field and the cones will change. The radical pairs will then switch between their single and triplet state, and through neural processes the birds will get directional information from this.

Cryptochrome

For this mechanism to work there must be a receptor that can receive this type of light information, and that also has the ability to form these radical pairs. Recent research suggests the flavoprotein cryptochrome to be this magnetoreceptor. Cryptochrome is a blue-sensitive molecule with the ability to absorb light and to form radical pairs. It contains pterin, a chromophore that is suggested to be the light-sensitive part of the molecule. Cryptochrome has been found in the retina of for instance European robins, garden warblers (*Sylvia borin*) and hens (*Gallus gallus*), and since they come from family lines separated over 95 million years ago, one can assume that this is a common model for most bird species. Experiments with the Europan robins, garden warblers and hens, along with other species, have proven that cryptochrome can form persistent, photo-induced radical pairs in birds' retinas.

Found in the UV-cones

Just a couple of years ago a group of scientist were able to locate the position of cryptochrome in the retina. They found cryptochrome in the UV-cones and in the UV-cones only. The UV-cones were also found to be evenly distributed on the entire retina, and the cryptochrome was uniformly aligned in the UV-cones, giving a good basis for magnetoreception. The scientists also suggested that it is the wavelength sensitivity of the cryptochrome itself that matters, not the sensitivity of the UV-cone, which was the belief earlier.

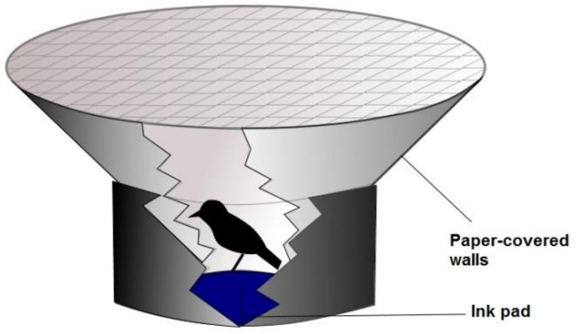

Figure 2. Emlen funnel. The birds are trapped in the cone-like cage. In the bottom of the cage there is an ink pad and when the birds walk in this, and then on the paper covered walls it will leave markings.

The different wavelengths

When experiments have been performed on birds, a pattern similar to the one mentioned above has been seen. The birds in the experiments were tested with light of different wavelengths. They were put in an Emlen funnel (figure 2) with a LED-lamp in the top. When the bird tried to move towards its migratory direction it left markings on the walls. Experiments have been performed in "white" (light with wavelengths from the entire visible spectrum), blue, turquoise, green, yellow and red light.

The wavelength pattern

When the results in the different experiments have been compiled, a pattern can be seen. Birds seem to be well oriented in blue, turquoise and green light, but not in yellow and red (figure 3). This indicates that the birds get too little information from light in the yellow and red part of the spectrum. If we consider the fact that scientists believe that it is the cryptochrome itself that determines the absorbance this is rather believable. Thanks to pterin, cryptochrome can

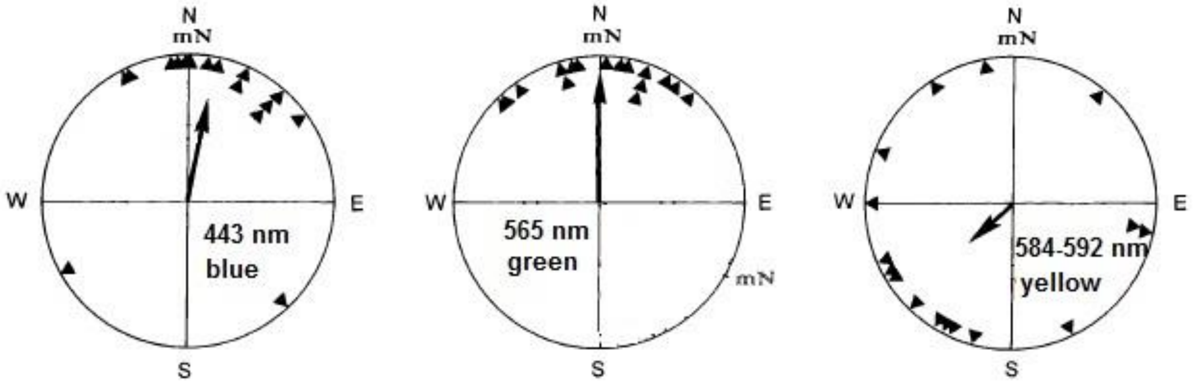

Figure 3. Chosen migratory direction of European robins during spring migration. The symbols in the circles show a mean of every tested birds' individual choice of direction. The arrows show the mean direction of all test results put together. *Revised after Wiltschko & Wiltschko (1999).*

absorb light in the blue part of the spectrum which can explain why also turquoise and green light seem to activate the receptor; the emission tails of the LED-lights used in the experiments mentioned above might extend into the part of the spectrum where pterin absorbs light. The emission tails of yellow and red light on the other hand are too far away, and will therefore not impact the cryptochrome.

Final words and thoughts

It is important to remember that the light conditions that the test birds were exposed to is not normal conditions for the birds. These experiments are performed to determine which wavelengths that actually matter for the birds, and therefore need to use extreme conditions, but during normal migration birds do get exposed to light with all kinds of wavelengths. Since the sun shines with white light, birds in the wild are virtually never deprived of any wavelength, even though the relative amounts of wavelengths might differ during the day.

A field in need for research

Many experiments remain to be performed before the entire mystery of birds' migration is solved. Many of the theories presented above are guess work and assumptions, so there is definitely a need for more research, especially about cryptochrome and its properties. Future research on birds should be done with lights with a more precise and narrow wavelength width, for example with a monochromator which have this ability. The light-dependence theory is a very promising theory; it's too much of a strike of luck if all the evidence for it is just a fortunate coincident.

Want to learn more?

For more information: Sundqvist J. 2013. Fåglars beroende av ljus vid migration. Individual Project in Biology, Uppsala University.