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Diurnal hawkmoth opsins evolving faster for greener vision

A diurnal coffee bee hawkmoth (*Cephonodes hylas*) just after emergence. Photo credit: Tokiho Akiyama.

Inhabiting our light-drenched cities, it can be difficult to imagine the true velvety blackness of a moonless night. Yet, on cloudless nights the darkness may not be all-enveloping; instead, the world of nocturnal creatures is flooded with starlight. 'Surprisingly, certain nocturnal moths can even see colour at night', says Tokiho Akiyama from The Graduate University for Advanced Studies (SOKENDAI), Japan. Yet, over the course of evolution, some nocturnal species have converted to a daytime lifestyle – to evade predatory bats and feast on diurnal blooms – although the temporal migrants retain many of the eye structures that made them so successful in the dimmest light. Knowing that nocturnal hawkmoths have made the transition to daytime living on three separate occasions – 29.2, 25.8 and 19.3 million years ago – Akiyama, Kentaro Arikawa and Yohey Terai (both from SOKENDAI) with colleagues from the Tokyo University of Agriculture, Japan, decided to find out how much the light-sensitive pigments, known as opsins – which are tuned to specific wavelengths of light – have altered as hawkmoths migrated from their starlit life to the dazzling daylit world.

'I caught the adult diurnal and nocturnal hawkmoths with an insect net when they came to flowers for nectar and also caught the nocturnal species with a light trap', says Akiyama, who succeeded in collecting four nocturnal and five diurnal species from the countryside outside Tokyo, Japan. To even up the number of nocturnal and diurnal species, Akiyama also nurtured oleander hawkmoth (*Daphnis nerii*) caterpillars until they developed into nocturnal adults to investigate the vision of all ten species. Then, Akiyama collected RNA from each species to assess expression of the three opsin genes – one each tuned to UV, blue and green wavelengths. And when they compared the amount of each opsin in the eyes of all ten hawkmoths, they found that the proportions of the UV, blue and green opsins differed little between the nocturnal and daylight-active moths; the green-tuned opsin dominated the moths' retinas (79.3–93.8%), with the blue opsin contributing 4.4–14.6% and the UV opsin composing 1.8–9.2%. The insects had not altered their opsin production patterns as they adapted to their new daytime lifestyle, so Akiyama took a closer look at the opsins themselves to find out whether they had adjusted to the brightness of day.

Sequencing the moths' opsin genes, assessing the differences between them and then arranging the genes into family trees, the team saw that the opsin genes of the daytime-active hawkmoths were evolving faster than in their nocturnal cousins, with the three families of daytime hawkmoths independently evolving the same amino acid alterations on seven different occasions. 'Diurnal species have evolved separately but have experienced similar evolutionary processes in their opsins to survive in the daylight environment', says Akiyama.

Then, the team calculated which wavelengths of light the three opsins from two nocturnal hawkmoths and two daytime-active hawkmoths absorb most strongly. They revealed that the blue opsin pigments in the daytime hawkmoths were absorbing greener wavelengths than the nocturnal moths, while the green pigments of the daytime-active moths had become more sensitive to bluer shades of green. And when Akiyama measured the sensitivity of the diurnal and nocturnal hawkmoths' eyes to all of the colours of the rainbow, from UV to red, both species of diurnal moths were more sensitive to shades of green than their nocturnal cousins.

'The diurnal hawkmoths may have enhanced colour discrimination ability in the blue–green range under daylight', says Akiyama, who is keen to learn more about the evolution of other light-sensitive genes.

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